RATIONAL BUILDING

BEING A TRANSLATION OF THE
ARTICLE "CONSTRUCTION" IN
THE DICTIONNAIRE RAISONNÉ
DE L'ARCHITECTURE FRANÇAISE

OF

M. EUGÈNE-EMMANUEL VIOLLET-LE-DUC

BY
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PREFACE.

WHILE preparing drawings for a large Cathedral Church in New York City, the article "Construction" of the "*Dictionnaire Raisonné*" was freely used and then the idea was conceived of translating it into English.

It has been appearing from time to time in the pages of a prominent architectural journal. Strange as it may seem, this section, which is as valuable as any in the dictionary to architects, archæologists and general readers, has never before been completely translated into English, although often attempted.

Great care has been exercised to obtain nice distinctions of meaning; the full force of the French idiom has been seized upon, and the endeavor has been to make this work appear as little like a bald technical translation as was consistent with the incisively keen remarks of the gifted author.

Eugène-Emmanuel Viollet-le-Duc was an architect and was born in Paris the 27th day of January, 1814.

He first studied architecture under Leclère, and became particularly interested in Gothic architecture, the serious study of which he pursued under the triple aspect of civil, religious and military constructions.

He also delved among the ruins of Greek and Roman art in Italy and Sicily, notably at Rome and at Taormina.

Afterward he visited the South of France, and made drawings of the principal monuments at Carcassonne, at Sens and at Toulouse.

Being Inspector-of-the-works of Sainte Chapelle about 1840 with Lassus, under the direction of Duban, he undertook the restoration of the former abbey-church of Vezelay under orders from the Commission for Historical Monuments, dependent at that time upon the Minister of the Interior.

In the next eight years he was employed in the restoration of the churches of Saint Père, of Montreale (Yonne) ; of the Town-hall of Saint Antonin (Tarn et Garonne) ; of St. Michael at Carcassonne ; of the Town-hall of Narbonne, besides the churches at Poissy (Seine-et-Oise) and Semur in the Côte d'Or.

The restoration of Notre Dame at Paris and the construction of the new sacristy were the result of a competition begun in 1845 ; in this work he was associated with Lassus. He finally completed the restoration of this basilica in 1856 with some interior paintings.

In 1846, he was chosen as architect of the Abbey of Saint Denis ; in 1849 he undertook the restoration of the fortifications of Carcassonne, the works of the Cathedral of Amiens and those of the Chapter-house at Sens.

He conducted or directed the restoration of Notre Dame de Chalons-sur-Marne, of the Cathedral of Laon and of the Château of Pierrefonds, after being appointed in 1853 one of the three inspectors-general charged with the administration of worship in the diocesan service of France.

At the end of 1863, he was appointed Professor of the History of Art and Aesthetics in the reorganized École des Beaux-Arts, but on account of the unruly conduct of the students, who were dissatisfied with the plan of reorganization as adopted by the Government and because they (the students) had not been consulted, he was compelled to leave and was replaced by M. H. Taine.

At this time, M. Viollet-le-Duc was one of the familiar habitues of the Tuileries and at Compiègne, and was one of the most heeded counsellors of the Empress.

During the siege of Paris, the artist became engineer and

took an active part in the organization of the auxiliary corps of the fortification, which, under his command and that of M. Alphand, rendered great services for the defence. Soon after, he abandoned his old political opinions and joined the ranks of the advanced Republican party, and while in this party, he was elected a Municipal Counsellor for the district of the Faubourg-Montmarte, in 1874.

He resigned his inspector-generalship of diocesan edifices, demanded full and complete amnesty as general counsellor of the Seine and praised the forbearance of the Democrats at the general elections of February, 1876, in the ninth arrondissement of Paris where M. Thiers resided.

Although he had contributed to the *Dix-Neuvième Siècle* since its foundation, he gave it up at this time as being too conservative, but renewed his connection the following year.

It was upon his report as a member of the Higher Commissions for International Exhibitions that the plans of the palaces in the Champs-de-Mars and on the Trocadero were adopted for the Exposition of 1878, united as they were by a gallery over the bridge of Jena. In January, 1878, he was reëlected Municipal Counsellor and occupied himself especially with questions relating to the Fine Arts, and he proposed to multiply statues of great men in Paris. He also sought to justify the use of the Phrygian cap on the statues of Liberty (February, 1879).

M. Viollet-le-Duc died suddenly at his country-house near Lausanne (Switzerland), the 17th of September, 1879, and was interred without any religious ceremony.

Amongst the numerous and valuable contributions he has left us, is the "*Dictionnaire Raisonné de l'Architecture*" from which the article "Construction" is taken. It will be seen that his wide practical experience, as well as varied travel and study, give his thoughts and deductions an authority rarely found, but which it is hoped will be duly appreciated in the following pages.

GEORGE MARTIN HUSS.

NEW YORK, January, 1895.

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CONSTRUCTION.

CHAPTER I.

General View.

CONSTRUCTION is a science; it is also an art — that is to say, the constructor must have knowledge, experience and a natural gift. Some are born constructors. Science which is acquired, can but develop the germs already deposited in the brain of those destined to give useful employment and permanent form to rough materials.

It is with peoples as with individuals: some are constructors from the cradle, others can never become so; the progress of civilization adds but little to this natural faculty.

Architecture and Construction must be taught, or practised simultaneously; Construction is the means, Architecture is the result. Nevertheless, there are works of architecture which cannot be considered as construction, and certain constructions which can scarcely be ranked among architectural works. Some animals construct: these cells, those nests, others mounds, burrows, hovels, wickerwork — *e. g.*, woven twigs. This is certainly construction, but it is not architecture.

Architectural construction is the employment of materials according to their quality and their adaptability, with the idea of satisfying a want by the most simple and solid means, giving to the constructed object the appearance of durability and proper proportions, subject to certain rules imposed by the senses — reason and human instinct.

The methods of the constructor must necessarily vary according to the nature of the materials, the means at his disposal, the requirements which he must satisfy, and the civilization in the midst of which he is placed.

The Greeks and the Romans were constructors, yet these two peoples set out from opposite starting-points. They did not employ the same materials, they worked them by different means, and satisfied wants which were not the same.

Accordingly, Greek monuments differ essentially in appearance from Roman. The Greek uses only the lintel in his constructions; the Roman uses the arch, and, in consequence, the vault: this alone proves sufficiently what very dissimilar constructions those opposite principles must produce, as well in the means employed as in their appearance.

We need not notice here the origin and the consequences of these two principles; we take Roman architecture at the point it had reached in the latter days of the Empire, for that is the only source from which the Middle Ages at first derived their ideas.

The principle of Roman construction is this: To establish points of support, offering by their position and their perfect cohesion masses sufficiently solid and homogeneous to resist the weight and the thrusts of the vaults; to distribute these weights and the thrusts upon stable piers, the inert resistance of which is sufficient.

Thus the Roman construction is but a concrete mass, skilfully calculated, by which all the parts devoid of elasticity hold one another by the laws of gravity and by their perfect adherence.

Among the Greeks, stability is obtained solely by the judicious observance of the laws of gravity. They do not seek the adherence of the materials; in fact, they neither know nor use mortars. In their monuments the weight acts only vertically; they, therefore, need but vertical resistance. Vaults being unknown to them, they do not require a support for oblique thrusts.

How did the Romans proceed to obtain passive resistance and

perfect adherence between all the inert and active parts of their constructions; that is to say, between the points of support and the vaults?

They built up homogeneous masonry by means of small materials such as pebbles and stones united by good mortar, and they enclosed these masses in an encasing of brick, of rough or cut stone. As to the vaults, they were formed of ribs of brickwork or stone in the body of the vaults, filled-in with béton thrown on centres of wood.

This method presented many advantages. It was expeditious. and edifices upon the same plan could be constructed in any country by employing the armies or the levies to erect them; it was durable, economical, and only required good direction, with a limited number of able and intelligent workmen, under whom a considerable number of simple hodmen could work. It rendered unnecessary the slow and heavy transport of cumbersome materials and of the machinery wherewith to raise them; it was, in fact, the consequence of the social and political state of Roman society.

The Romans, however, built edifices, etc., after the same manner as the Greeks, such as their temples, their basilicas; but these monuments are an importation, and must be placed outside of the true Roman construction.

The barbarians who invaded the Roman provinces did not bring with them any arts or methods of construction, or, at least, the elements which they introduced in the midst of the expiring Roman civilization could have had but a very feeble influence. They found monuments already constructed, and they made use of them. Long after the appearance of the barbarians upon the Gallo-Roman soil, there still existed a large number of ancient edifices, which would indicate that the Germanic hordes did not destroy them all. In fact, they often tried to repair them, and soon to imitate them.

But, after such long disasters, the traditions left by the Roman constructors must in a great measure have been lost; and, under the Merovingians, the buildings erected in Gaul were but barbaric

reproductions of the ancient constructions either spared by war, or which had been able to withstand prolonged neglect.

The few remaining monuments antedating the Carlovingian period present constructions in which but a slight reflection of the art of the Roman is discernible; they are but rough imitations of the numerous edifices, the ruins of which still covered the soil.

It is only during the reign of Charlemagne that we find constructors making some attempt to dispel the ignorance in which the preceding ages had been plunged.

The continuous relations of this prince with the East, his connection with the Lombards, with whom the last traditions of the ancient art seem to have taken refuge, supplied him the means of drawing to him and into the countries under his rule builders whom he knew how to utilize with remarkable zeal and perseverance. His aim certainly was to revive the Roman arts, but the sources to which he had to apply for this result had been greatly modified in their origin.

Charlemagne could not send architects to study the monuments of ancient Rome, for he had none: he could ask for artists, engineers and skilled workmen only from the East, Spain or Lombardy, the countries which alone possessed any. They brought with them methods that had already deviated from those of antiquity.

The Carlovingian revival produced, therefore, quite different results from those probably expected by its author. After all, the object was attained, as the new elements imported into the West soon produced notable efforts, and after that period the arts progressed rapidly.

It is the history of this advancement in relation to construction only which we shall try to describe, referring our readers to the word "*Architecture*" for all which appertains to the development of this art from the tenth to the sixteenth century.

During the existence of the Roman Empire, whether at Rome or in Byzantium, it is easy to recognize that vaults were the dominant motive of the constructors. From the barrel-vault they quickly arrived at the groined or intersecting vault, and from the dome supported upon a circular wall or drum to the hemispherical vault borne upon pendentives, as in the construction of the Church of Santa Sophia; this being an immense step which established a line of demarcation between the ancient Roman construction and that of the modern age.

Neither Rome, Italy nor Gaul could show one single Roman edifice in which the hemispherical vault was supported by pendentives. The Church of Santa Sophia is the first[1] to supply us with an example of that kind of construction, and, as every one knows, it is the largest dome in existence.

How could the Roman architects established in Byzantium manage to conceive and execute a construction of this kind? This we will not try to unravel. We take the fact, where, for the first time, it shows with undoubted grandeur and freedom.

To cover a circular enclosure with a hemispherical vault was quite a natural idea, and was adopted in remote antiquity; to introduce cylinders or barrel-vaults in the circular drum was but a natural consequence of the first step. But to erect a hemispherical dome upon a square plan — that is to say, upon four isolated piers placed at the angles of a square — was not a deduction from the first principles; it was an innovation, and one of the boldest.

The builders whom Charlemagne brought from Lombardy and the East, to the West, did not, however, bring with them this mode of construction; they contented themselves with erecting, as at Aix-la-Chapelle, vaults with octagonal or circular bases upon drums rising from the foundation. It was later on that the constructions derived from the Byzantines obtained a direct influence in the West. As to the building methods of the Carlovingian constructors, they approached the Roman methods, which consisted in massive

[1] Note to be added at end of chapter.

rubble-work enclosed in facings of brick, of rough or dressed stone, or else of stone alternating with courses of brick, the whole bedded in thick joints of mortar, as shown in Figure 1.

Fig 1.

We indicate at *A* courses of triangular bricks, presenting their largest side to the face, and at *B* the courses of stone, more or less regular, and presenting a front, for the most part square, to the faces.

At *C* is shown a brick of which the thickness varies from 0.04 c., to 0.05 c., and at *D* a facing stone.

This is Roman construction roughly executed. But the Romans seldom employed this method unless they wanted to cover the facings by a veneer of marble or of stucco. When they made facings with cut-stone, they laid these without mortar upon their natural beds, leaving them a wide bed, so that these facings might really become a help, capable of resisting a pressure which the wall alone could not have supported.

From the first days of the Carlovingian period, constructors also wanted to erect edifices faced with cut-stone, upon the style of certain Roman buildings; but they did not possess the powerful means employed by the Romans. They could neither transport nor much less raise to any considerable height blocks of stone of a large size. They, therefore, contented themselves with the appearance

only; that is, they made facings composed of a veneering, generally of stone set on edge and of thin scantling; carefully avoiding the settling, and filling the hollows between these facings with rubble bedded in mortar.

They sometimes went so far as to try to imitate the construction of Roman work by placing these facings of stone upon dry joints without mortar. It is needless to say how defective this construction was, the more so that their mortar was poor, their lime badly burned or badly slaked, their sand adulterated with earth, and their rubble extremely irregular.

Sometimes they took a middle course; that is, they erected facings of small cutstones held together by thick beds of mortar.

These efforts, these gropings, did not constitute an art. If, in the details of construction, architects gave evidence of an imperfect knowledge, if they could but so poorly imitate the process of the Romans, it stands to reason that, in the variety of their buildings, they found themselves repeatedly cornered by difficulties which they were not in a condition to surmount: wanting in knowledge, possessing only precedents almost obscure, having no able workmen nor powerful engines, groping their way, they had to make, and did make, tremendous efforts to erect small buildings, to render them solid and, above all, to vault them. It is there that, in the Carlovingian monuments, one can always recognize the incompetence of the constructors, their embarrassment, their uncertainty, and often the discouragement resulting from incapability. From this very ignorance of ancient methods, and especially from the continued efforts of the builders from the ninth to the eleventh centuries, there sprang up a new art of building: the result of unfortunate experiments at first, but which, repeated with perseverance and attended with uninterrupted improvement, marked out a road not already explored. No less than three centuries were needed to instruct these barbarians; but they were able, nevertheless, after such slow efforts, to congratulate themselves upon having opened to

future constructors a new era, which borrowed but little from the arts of antiquity.

The stern necessities by which these first constructors found themselves confronted compelled them to fall back on their own resources in preference to the studies of ancient monuments, which they understood but very imperfectly, and which in the greater part of the Gallic provinces existed only in a state of ruin. Ever ready to imitate foreign works, they submitted these to their own imperfect processes, and in thus transforming them they made them contribute towards a unique art, in which reason prevailed over tradition. That was a hard school: resting with uncertainty upon the past, finding itself confronted by the needs of a civilization where everything had to be created, possessing but the elements of the exact sciences, it had no guide other than experiments; but this method, if not the quickest, had, at least, the advantage of making practical observers, who were careful to collect all the improvements which could help them.

In the edifices of the eleventh century construction already makes sensible progress, which is but the consequence of errors avoided with more or less skill; for an error and its effects instruct men more than perfect works.

They had no longer at their command the means employed by the Romans in their undertakings: short of workmen, of money, of means of transportation, of connections, of roads, of tools, of appliances, confined in provinces, separated by the feudal administration, the constructors could only count upon very feeble resources; and meanwhile, at this time [the eleventh century], they were already called upon to erect vast monasteries, palaces, churches and fortifications.

It was necessary that their industry should supply all that Roman genius had known how to organize, all that the state of our modern civilization furnishes us in profusion.

It was urgent to obtain great results at little expense [for then

the West was poor], and to gratify numerous and pressing needs upon a soil ravaged by barbarism.

It was incumbent upon the constructor to procure the materials, to find the means of transporting them, and to fight against the ignorance of unskilful laborers, and that he himself should make his own observations as to the quality of the lime, of the sand, of the stone, and to look after the storing of the lumber. He not only had to be the architect, but the quarrier, the surveyor, the modeller, the superintendent, the carpenter, the lime-burner, the mason, and could be assisted only by his own intelligence and reason as an observer.

To-day, when a lawyer or a business man has a house built without the assistance of an architect, it is easy for us to consider these first efforts as rude; but the genius which a builder of that period required and evinced in the erection of a hall or a church was certainly superior to that demanded from an architect of our time, whose operations may be carried on without any knowledge of the first elements of his art, a thing which too often occurs.

In those days of barbaric ignorance, the most intelligent, those who had raised themselves by their own genius above the common workman, were alone capable of directing a structure, and the superintendence of buildings, necessarily limited among a restricted number of superior men, for that reason produced original works, in the execution of which the reasoning faculties were largely called upon, where calculation is apparent, and the form bears that stamp of superiority which is the distinguishing mark of buildings ably planned, subservient to the needs and customs of a people.

It must clearly be recognized, if even we were to be designated as barbarians ourselves, that the beauty of a structure does not lie in the improvements wrought by an advanced civilization, or a state of highly developed industry, but in the judicious employment of the materials and the means placed at the disposal of the constructor. With our numerous materials, with the metals delivered to us from

our workshops, with the multitude of skilled workmen in our cities, it sometimes happens that we erect a structure defective, absurd, ridiculous and without reason or economy; whereas with ashlar and wood, a good, handsome and sensible structure can be made.

So far as we know the variety or the perfection of the material employed has never proved the merit of him who has used it; and excellent materials are detestable if used in disregard of their proper place and function, by a man devoid of knowledge and of sense.

What one may be justly proud of is the good and proper employment of the materials, and not their quantity or quality.

The foregoing written under the form of a parenthesis, is to impress upon our readers that we should not despise the constructors, who had at their disposal only stone badly quarried, bad stone from the site, badly burned lime, imperfect tools and weak implements; for with such coarse appliances, these constructors teach us excellent principles, applicable at all times.

And the proof is what they did, that is, they formed a school which from the point of view of practical as well as theoretical science, and of the judicious employment of materials, arrived at a degree of perfection unsurpassed in modern times. Let those who teach architecture without having practised the art, judge the architectural productions of ancient and modern civilization by mere appearance, by superficial form which impresses them; but we who are called to construct must seek our instruction through the attempts and the progress of these ingenious architects, who having nothing to draw from were compelled to solve the problems which were imposed by contemporary society.

To consider the builders of the Middle Ages as barbarians, because they gave up building by Roman methods, is to be unwilling to take account of the state of the new society, — is to despise the profound modifications introduced into their customs by Christianity, founded upon the genius of the Western nations: it is to efface several centuries of slow but persevering toil, which was

taking place in the bosom of society; toil which has developed the most active and the most vital elements of modern civilization.

No one admires antiquity more than we do, no one is more inclined than we to recognize the superiority over the modern arts of the noble art epochs of the Greeks and Romans; but we are born in the nineteenth century, and we cannot ignore the fact that between antiquity and our own times there has been a great birth of ideas, of needs, of means unknown to the ancients.

We must take account of the new elements, of the tendencies of a new society. Let us regret the disappearance of the social organization of antiquity, let us study it scrupulously, let us have recourse to it; but let us not forget that we live under neither Pericles nor Augustus; that we have no slaves; that three fourths of Europe are no longer plunged in ignorance and barbarism to the great advantage of the other fourth; that society is no longer divided into two unequal portions, the stronger absolutely controlled by the other; that our needs are limitless; that the machinery is complicated; that industry analyzes incessantly all the means placed at the disposal of mankind and transforms them; that tradition and formulas are replaced by reasoning, and that, in short, art in order to exist, must recognize the environment amid which it is developing. Now, in the Middle Ages, the construction of buildings had entered upon this entirely new path.

Lament it, if you will; but the fact does not the less exist, and we cannot hinder yesterday from being the eve of to-day. What is better, then, it seems to us, is to seek in the labor of yesterday what is useful to us to-day, and to see whether this labor has not led to the work of the present. This is more rational than to despise it.

It has often been maintained that the Middle Ages is an exceptional epoch, having nothing in common with that which preceded it nor with that which followed, foreign to the spirit of our country and to modern civilization. That is perhaps tenable from the political point of view, although such a state of affairs is unique in the

history of the world, where everything is part of a series; but the party spirit entering, there is no paradox which does not find supporters.

In architecture, and above all, in construction, there is not possibly room for party spirit, and we do not see that the principles of civil liberty, that modern laws, under the régime of which we have the good fortune to be born, are in any way attacked, though it may be shown that the builders of the twelfth century knew how to construct well, that those of the thirteenth century were very ingenious and free in the employment of means; that they sought the most simple and least expensive processes to carry out the programme which had been imposed upon them; that they reasoned correctly and knew the laws of statics and the equilibrium of forces.

A custom may be odious and oppressive: abbots and feudal lords might, if you please, be dissipated, exercising an intolerable despotism, yet the monasteries or the castles in which they dwelt, might, nevertheless, be built with wisdom, economy and wide range in the employment of materials.

A building is not *fanatical, oppressive, tyrannical*— these epithets have not yet been applied to a mass of stone, wood or iron. A structure is good or bad, appropriate or devoid of reason. If we find nothing to take from the feudal code, that does not imply we have nothing to learn from the constructions of that time.

A parliament condemns unhappy Jews and sorcerers to be burned alive, but the hall in which that parliament sits may be a structure that is more appropriate and better built than that in which our magistrates apply wise laws with an enlightened spirit.

A man of letters, an historian, says, in speaking of a feudal castle: "This retreat of brigands, this dwelling of petty despots, tyrannizing over their vassals, warring with their neighbors . . ." Immediately every one cries out against lord and castle. In what are these edifices the accomplices of those who had them built, above all, if the masons and laborers suffered the employers' tyranny? Did

not the Greeks show on many occasions the most odious fanaticism? Does that prevent our admiring the Parthenon or the Temple of Theseus?

It is high time, so we think, that we architects should no longer allow ourselves to be deceived by the talk of those who, strangers to the practice of our art, judge of works which they cannot understand, of which they appreciate neither the plan, construction nor utility, and who, moved by their feelings or their personal tastes, by secluded studies and a narrow spirit of party, hurl anathemas upon artists whose efforts, science, and practical experience, are to us, even to-day, of great assistance. Little does it matter to us that the feudal lords were tyrants, that the clergy of the Middle Ages were corrupt, ambitious and fanatical, if the men who built their dwellings were ingenious, if they loved their art and practised it with knowledge and care. Little does it matter to us that a prison has shut in living beings for years, if the stones of that prison were well enough laid to offer an unsurmountable obstacle; little does it matter to us that a grille has closed a chamber of torture, if the grille be well designed and the iron well forged.

The confusion between the institutions and the products of the arts ought to have no existence for us, who seek our advantage wherever we may find it. Let us not, to our own detriment, be the dupes of exclusive doctrines: we may blame the customs of past times if they seem bad; but not proscribe their arts before discovering whether we have not any advantages to derive from the study of them.

Let us leave to enlightened amateurs the task of disputing about the preëminence of Greek architecture over Roman architecture, of the latter over the architecture of the Middle Ages; let us leave to them the discussion of these unanswerable questions; let us, if we have nothing better to do, listen to their discoursing of our art without knowing how a panel is drawn or a stone cut or placed — it is not allowable to practise medicine or even pharmacy without being a physician or apothecary; but architecture! that is another thing.

To understand the first efforts of the builders of the Middle Ages, it is necessary first to know the principles which they laid down, and the practical means then in use.

The Romans, masters of the world, having known how to establish a regular, uniform government in the midst of so many allied and conquered peoples, had in their hands resources which were absolutely lacking in the provinces of the Gauls, divided into little States and innumerable parts, by the establishment of the feudal system.

The Romans, whenever they wished to cover a country with monuments of public utility, could throw upon that point at a given moment, not only an army of soldiers used to the work, but would impress the inhabitants (for the system of requisition was practised on a vast scale by the Romans), and obtain, by the aid of that multitude of hands, prodigious results. They adopted, in order to construct promptly and well, methods which accorded perfectly with the social state.

Had the builders of the Middle Ages wished to employ these methods, where would they have found this army of workmen?

How obtain in a country without stone, for instance, the materials necessary for building, when the old Roman roads were destroyed; when money was lacking to buy materials and obtain beasts of burden; when the provinces were almost always at war with one another; when each abbot, each lord, regarded himself as an absolute sovereign, so much the more jealous of his power in proportion as the country over which it extended was small?

How organize regular levies of men where many powers quarrelled for preëminence, where the inhabitants were scarcely numerous enough to cultivate the soil, and where war was the normal condition?

How get together the enormous mass of materials necessary for the least extensive construction? How feed the workmen at one place? The religious orders were the first who could by themselves

undertake important building: First, because they could assemble at one place a number of workmen sufficiently united by a single thought, subject to discipline, freed from military service, possessors of the land on which they lived; secondly, because they amassed property which grew rapidly under a regular administration; because they joined in amicable intercourse with neighboring establishments because they ploughed up and rendered wholesome uncultivated lands, laid out roads, acquired by gift or purchase the richest quarries, the best woods, built workshops, offered to the peasants guarantees relatively certain, and peopled their lands thus rapidly to the detriment of those of the lay nobility; thirdly, because they were able, thanks to their privileges, and the comparative stability of their institutions, to form with their monasteries schools of artisans, subject to a regular apprenticeship, clothed, fed, maintained, working under the same direction, preserving traditions and recording improvements; fourthly, because they alone, at that time, extended their influence to a distance, in founding establishments subject to the mother abbey; because thus they continued to profit by all the partial efforts that were made in countries very diverse in climate, manners and customs. It is to the activity of the religious orders that the art of construction owes its rise from barbarism in the eleventh century.

The Order of Cluny, as the most important (see "*Architecture Monastique*"), the most powerful and the most enlightened, was the first which had a school of architects whose new principles were to produce in the twelfth century monuments freed from the last Roman traditions. What are these principles? How did they develop? This we must examine.

NOTE p. 5. [1] In the actual width of the dome, S. Sophia (104 feet) is not the largest. The Pantheon is 142 feet, 6 inches.

CHAPTER II.

PRINCIPLES.

IN order that new principles may develop, it is necessary in every case that new conditions and needs show themselves. When the Order of St. Benedict was reformed in the eleventh century, the reformers aimed at nothing less than an entire change in a society which, scarcely born, was already falling into decay. These reformers, being able men, commenced by abandoning the rotten traditions of ancient society; they set out with nothing, desiring to continue no longer those dwellings which, being at the same time sumptuous and barbaric, had until then served as refuges for the corrupt monks of preceding centuries.

They built themselves wooden cabins, lived in the midst of the country, taking life as men would when left solely to their industry in a desert. These first steps were a persistent influence, even when the increasing riches of the monasteries and their importance in the midst of the society brought them to change their huts for dwellings of a durable nature, luxuriously built. To satisfy the absolute need is always the first law observed, not only in the planning of the buildings but in the details of the construction; never to sacrifice solidity to a vain appearance of richness is the second.

Stone and wood are always stone and wood, and whether we use these materials in a structure in greater or less quantity their function is the same among all peoples and in all times.

However rich and powerful the monks might be they could not hope to build as the Romans had done. They endeavored then to raise solid and durable structures, with economy (for they intended building for the future).

. To use the most ordinary Roman method, that is to say, in making their structures of masses of rubble, enclosed between facings of brick or ashlar, demanded more laborers than they had at their disposal. To construct by means of enormous blocks of hewn stone, carefully cut and placed, required means of transportation far beyond their facilities, lacking as they did firm roads, a considerable number of skilled workmen, many beasts of burden, costly tools or machinery difficult to obtain.

They pursued a middle course. They raised the principal points of support, employing for the dressings cut stone, as a casing, and filled-in

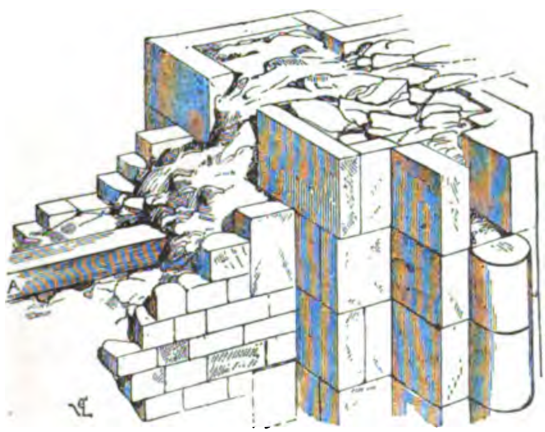


Fig. 2.

with rubble; for filled walls, they adopted a thin facing of scappled ashlar, or else stone blocks enclosing a mixture of pebbles and mortar.

Figure 2 gives an idea of this kind of construction. In order to bind together the different parts of the buildings, to bond the

walls in their length, they sunk in the masonry at different heights, under the supports of the windows, beneath the cornices, longitudinal beams of wood, as we have represented in *A*. (See "*Chaînage*.")

In these constructions the stone is economized as much as possible; no piece shows any gaps; all are set in the most economical manner; the faces are but just sufficient and yet are executed with the greatest care; not only are the facings tooled, but also the beds and the joints, and these stones are set on the earth without mortar, after the Roman arrangement.

This kind of building is shown in the great monastic structures of Cluny, of Vezelay, and of La Charité-sur-Loire (eleventh and twelfth centuries).

The materials employed by the monks are those which they could procure for themselves in the vicinity, in the quarries which they owned. They employed them in so far as their good qualities and their defects would allow. If these materials showed faults, if the stone was split by the frost, the monks not being able to obtain other, except at great expense, took pains to put it in the best condition, and, in order to protect these materials from injury by dampness and the effects of frost, they sought to withdraw them from atmospheric agencies, by covering them with projecting roofs, and by keeping them from the ground outside, by courses of stone, which they purchased from more distant quarries.

There is always in the works of men who only rely on their own resources, and their own forces for action, a certain amount of intelligence and energy, of great value in the eyes of those who can see; even though the work is imperfect, and otherwise rough, it contains intelligence and energy not found in the works produced by men more civilized, but to whom industry furnished many elements, and who have no efforts to make to satisfy all their needs. The primitive seekers, then, often became masters, and their efforts a costly education, for more intelligence was obviously necessary to

produce at that period, when all resources were lacking, than in our own, when they are within the reach of the most ordinary minds.

The Roman buildings, by reason of the absolute stability of their points of support and the perfect concretion of all the upper parts (a result obtained, as we have already said, by the means of immense resources), presented immovable, passive masses, as if they had been monuments cut from a single block of tufa. The Romanesque architects, not having at their disposal such powerful means, soon recognized that their buildings did not present a united and concrete whole, a perfectly stable agglomeration; that the piers, formed by a veneering of stone, enclosing a mass of rough stones put together often with mediocre mortar, that the walls not bonded in all their height, suffered from unequal settling which caused ruptures in the buildings and in consequence serious accidents.

It was necessary then to seek for proper means of overcoming these effects. Beginning with the eleventh century, the Romanesque architects wished, for reasons elsewhere set forth (See "*Architecture*"), to vault most of their great edifices. They had inherited the Roman vaults, but they were debarred from the powerful means which the Romans adopted for supporting them. Their intelligence had to make up for this lack of power. The Roman vault can only sustain itself by having the points of support perfectly stable, for this vault, whether cradle, groin or half-spherical, forms a homogeneous crust without elasticity, which breaks to pieces if crevices occur unexpectedly in its curve.

Wishing to make vaults like those of the Romans, and being unable to give them perfectly stable supports, it was necessary for the Romanesque builders to find a new method of holding them firmly, with reference to the unstability of the supports destined to carry and buttress them. The task was not easy to fulfil; moreover, the experiments, the endeavors, the attempts had been numerous; but nevertheless, from the beginning of these attempts, we see arising a new system of building, and this system is founded on the principle

of elasticity, replacing the principle of absolute stability adopted by the Romans. The Roman vault, save for rare exceptions, is built of rough stone concrete; if it is strengthened by arches of brick, these arches are buried in the thickness of the concrete, and become one with it. The Romanesque builders, instead of building the vault of concrete, constructed it of unhewn stones, sunk in mortar, but set like arch-stones, or of stones hewn and forming a small facing of masonry; and even these vaults showed a certain elasticity, if a movement was felt in the supports, in consequence of the joining of the arch-stone, and did not break like a homogeneous crust, but followed the movement of the piers. Yet this first modification did not entirely reassure the Romanesque builders; they fixed under these vaults, from point to point, at the height of the supports of greatest resistance, transverse arches faced in stone, under the soffits of the vaults. These transverse arches, a species of permanent centre, elastic, like every arch composed of a certain quantity of arch-stones, followed the movement of the piers, yielded to their settling down, and separating and supported thus, as a wooden centre would have done, the vaults of masonry built over them.

The Romanesque builders had taken from the Romans the groined vault, built on a square base and formed by the intersection of two half-cylinders of equal diameter. But when they wished to raise vaults upon piers, placed at the angles of parallelograms, the Roman groined vault could not be used; they adopted, in this case, the cradle-vault, or half-cylinder continued without intersection, and at the height of the piers, they reinforced these cradle-vaults by transverse arches of dimension stones, upon which they relied to avoid the injurious effects of a longitudinal rupture in these cradle-vaults, in consequence of a movement in the piers. Once again, and we insist upon this point, it was a permanent centering. Nevertheless, the obstacles and the difficulties seemed to arise in proportion as the builders believed that they had found the solution of the problem. The effects of the thrust of vaults, so perfectly recognized by the

Romans, were almost unknown to the Romanesque builders. The first among them who had the idea of fastening a semicircular cradle-vault upon two parallel walls, thought that he had certainly avoided forever the disadvantages attached to visible timbers, and that he had combined a structure at the same time solid, durable and of monumental aspect. His illusion was destined to be of no long duration, for, the centres and planks being removed, the walls leaned outwards and the vault fell between them. It was necessary then to find suitable means of preventing such catastrophes.

At first they reinforced the walls by exterior buttresses and by piers erected in the interior: then, at the height of these buttresses and piers, they fixed transverse arches beneath the cradle-vaults. By imbedding timbers lengthwise, in the thickness of the walls, from pier to pier at the springing of the cradle-vaults, they thought it possible to check their thrust between the piers. It was never more than a temporary remedy; if some buildings thus vaulted, resisted the thrust of the cradle-vaults, a large number fell to pieces some time after their construction.

But it is necessary that our readers have an exact idea of this kind of construction. We give (Fig. 3) the whole and the details. In *A* we have the interior piers carrying the transverse arches *E*; in *B*, the exterior buttresses destined to resist their thrust; in *C*, the beams of wood holding the cradle-vault *D*, at its springing. In order to reduce the spreading of the transverse arches as much as possible, the constructors allowed a considerable projection of the capitals *G*.

If the vaults thus planned were fixed upon piers solidly enough built in materials well joined or very heavy, if the walls were thick and massive from top to bottom, if the buttresses jutted out sufficiently, and if the transverse arches and consequently the piers were not too far apart, these cradle vaults, reinforced by secondary arches, might be maintained.

But, if, as happened in naves bordered with aisles, the walls rested upon the archivolts and the detached piers; if these detached piers

which they tried always to make as slender as possible in order not to obstruct free movement and the view, did not present a surface sufficient to receive the exterior buttresses rising above the vaults at the lower sides, then the upper cradle-vault, in spite of its transverse arches, or with its transverse arches, little by little bent

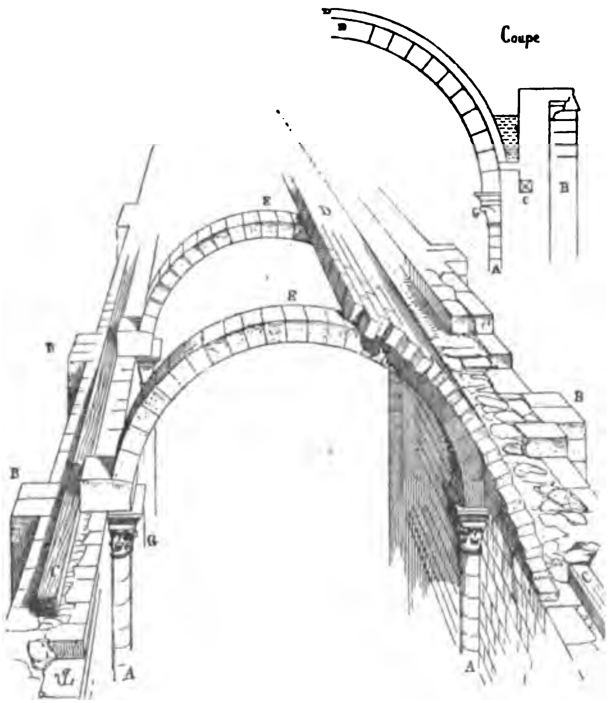


Fig. 3.

the walls and the piers outward, and the whole structure fell apart. As early as the end of the eleventh century, many churches and halls thus vaulted, built half a century before, fell in ruins, and it was necessary to reconstruct them. These accidents were a lesson to the builders; they gave them a chance to observe certain phenomena in

statics of which they had not had any idea; it made them recognize that these beams of wood sunk in the masonry and deprived of air, speedily became rotten, and that the void they left could only hasten the destruction of the buildings; that the walls having begun to bend, the pressure of the vaults increased in direct ratio with their separation; that in short, if the cradle-vaults were built over naves with aisles, the disorders caused by the spreading of the high vaults were such that it was impossible to maintain the piers and the walls in a vertical position.

Nevertheless the moment had not yet come when the builders were to solve exactly the problem of the stability of vaults raised upon parallel walls; they had still to make attempts to avoid the effects of the pressure upon the lateral walls. The Romanesque builders knew that the groined vaults presented the advantage of exercising pressure and thrust only upon the four supports receiving their skewbacks. Recognizing that the cradle-vaults exerted on the tops of the walls a continual pressure, they sought to do away with them, and to replace them by groined vaults, even in the naves composed of oblong compartments, in order to bring all their weight and their pressure to bear upon the piers that they hoped to render stable. But, as we have said above, the Roman groined vault can be built only over a square space; it was necessary then, to find a new combination of groined vaults adapted to the form of a parallelogram.

It was not practicable to lay out these vaults geometrically, and it was only by experiment that they succeeded in constructing them.

Already, during the eleventh century, the builders had constructed vaults which partook of both the dome and the groined vault, in that these vaults, instead of being formed by the intersection of two cylinders at right angles are produced by four semicircular arches joining the four piers, and two diagonal arches which are themselves semicircular, and hence present a longer radius than those of the first four.

CHAPTER III.

Roman and Romanesque Vaults.

WHEN we know the means employed to construct a groined vault, we easily comprehend the reason for the modification of the Roman groined vault. To make a vault, it requires wooden centres upon which to place the courses. Now to make a Roman groined vault, it is necessary to make four semicircular centres and two diagonal centres, whose curve is given by the meeting of the half-cylinders; the curve of the diagonal centres is not a semicircle, but an ellipse that is obtained by means of ordinates, as shown in Figure 4.

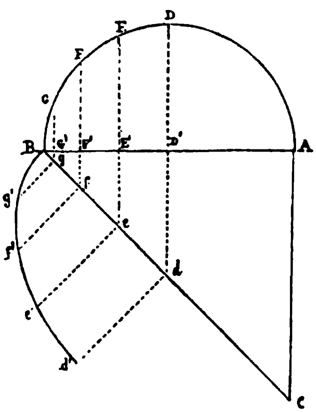


Fig. 4.

. Let A B represent the diameter of the cylinders, and B C the horizontal trace of the plane in which the two cylinders A B and A C meet. Working upon a quarter-section, and dividing the revolved semicircle into a certain number of equal parts — D E, E F, F G, G B — we let fall perpendiculars from these dividing points, D, E, F, G, upon the diameter A B, prolonging them to meet the

diagonal $B\,C$. We thus obtain upon that diagonal the dividing points, d, e, f, g; from these points, erecting perpendiculars upon the diagonal $B\,C$, and taking upon these perpendiculars the distances $d\,d'$, equal to $D\,D'$, $e\,e'$, equal to $E\,E'$, etc., we determine the points d', e', f', g', through which the curve of the intersection of the two half-cylinders must pass. This curve, having a versed sine (*flèche*), $d\,d'$, equal to the radius $D\,D'$, and a diameter $B\,C$, greater than the diameter $A\,B$, cannot be a semicircle. Although very simple, this geometrical drawing appeared too complicated to the Romanesque builders. Accordingly, having described a semicircle upon the diameter $A\,B$, in order to cut out the timber centres of the four arches generating the vault, they described a second semicircle upon the diameter $B\,C$, in order to cut out the two diagonal centres. Thus the keystones d of meeting of these two diagonal centres were found to be situated on a higher level than the keystones D of the generating arches; and the vault, instead of resulting from the meeting of two half-cylinders, was a nameless compound of curved surfaces, but resembling a dome. This elementary demonstration is necessary, for it is the key to the whole system of vaults in the Middle Ages.

This first result, due rather to ignorance than to design, was, nevertheless, one of the most fertile principles in the history of construction. Moreover, it indicates something different from dense ignorance; it denotes a certain liberty of thought in the use of the means of building, the importance of which is considerable, and, in fact, once freed from Roman traditions, the builders of the Middle Ages were more and more consistent with their principles. They soon comprehended the full extent of these, and gave themselves up freely to them; nevertheless, let us follow them step by step.

The problem was, then, the principle once admitted of the Roman groined vault modified in this way, to apply these vaults to oblong plans, for the builders recognized the danger of wide barrel or cradle vaults; that is, barrel-vaults having a wide span.

Let *A*, *B*, *C*, *D*, then (Fig. 5), be the plan of a compartment of a nave which is to be covered by a groined vault.

Let *A*, *E*, *B* be the semicircular extrados of the transverse arches in plan, and *A*, *F*, *C*, the semicircular extrados of the wall-arches likewise in plan.

It is clear that the radius *H F*, will be shorter than the radius *G E*; therefore, the keystone *E* will be higher than the keystone *F*.

If we describe a semicircle upon the diagonal *A D*, as being the curve on which the vaults generated by the semicircles *A*, *E*, *B*, and *A*, *F*, *C*, must meet, it will result that the groins *A I*, *B I*, *D I* and *C I*, instead of projecting throughout all their extent, will be, on the contrary, in retreat for almost two-thirds of their length, and chiefly so in approaching the keystone *I*.

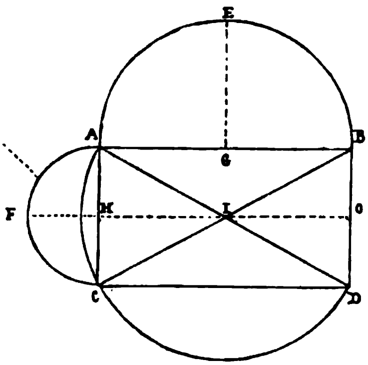


Fig. 5.

Thus, let Figure 6 be the transverse section of the vault through *H O*.

Let *H′F′* be the section of the wall-arch, *H′ I′ O′* the vertical projection of the diagonal *A D* or *B C*.

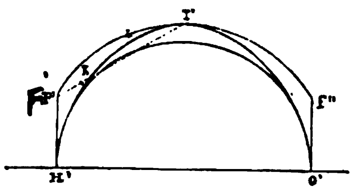


Fig. 6.

The straight line drawn from the keystone *F′* to the keystone *I′* leaves a segment of a circle, *K*, *L*, *I′*, above that line, whence it would result that this portion of the vault must be convex on the intrados, instead of being concave, and that, consequently, it would not be constructible.

Placing, then, wall-arches and transverse arches upon the diagonal

arches and courses of planks to close the triangles of the vaults in masonry, the builders covered these courses with a thick mass of earth, following a curve given by three points, F, I', F''; that is to say, given by the summits of the diagonal and wall arches; thus the diagonal groins were made projecting, and upon this mass they placed rows of stones parallel with the section $F'I'$, to close the vault.

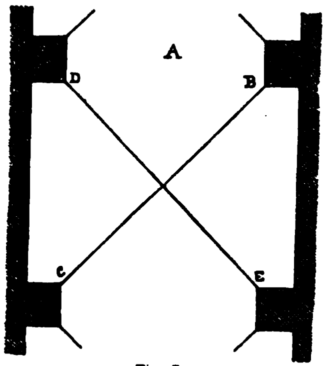


Fig. 7.

The result of these blind efforts was that the groined vaults were no longer the intersections of cylinders or cones, but ellipsoidal. The first difficulty being cleared, improvements were not slow to develop. But first, how, by what mechanical processes were these vaults constructed? The Roman groined vault, built in compartments, had no transverse arches; it rested upon piers or projecting columns, as represented in Figure 7, — that is to say (see the horizontal plan A of one of these vaults), the diagonals $B\,C$ and $D\,E$, formed by the intersection of two half-cylinders of equal diameter and forming projecting groins, rested upon the projecting corners of the piers.

But the Romanesque architects having at first reinforced the large cradle-vaults by transverse arches, as shown in Figure 3, and having come to replace these semicylindrical vaults by oblong groined vaults, kept the transverse arches; they could not do otherwise, since the diagonals of these vaults were semicircular, and their summit rose above the summit of the arches, whose diameter was given by the distance between the piers.

In order to make ourselves clear, let Figure 8 be the longitudinal section of a Roman groined vault composed of compartments; the

line $A\ B$ is horizontal and is the section of the longitudinal semi-cylinder.

Let Figure 8*b* be the longitudinal section of a Romanesque groined vault in oblong form; then the line $A\ B$ is a succession of curves, or at least of broken lines uniting the points C and D, the summits of

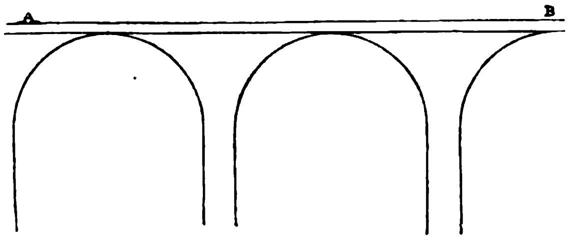


Fig. 8.

the transverse arches, to the point of meeting, E, of the diagonal semicircles. They are obliged, necessarily, to preserve under the points C and D of the projecting arches, transverse arches which, as

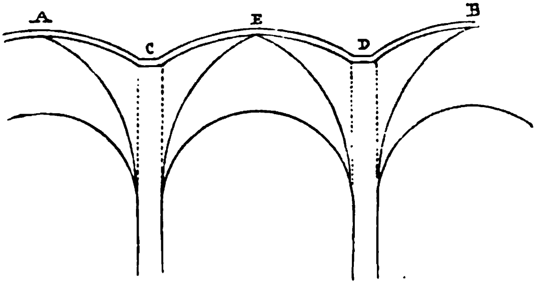


Fig. 8*b*.

we said before, were only permanent centres. From that time the diagonal groins had to take their point of departure in the rear of the projection of the piers or columns; these being destined only to carry the transverse arches; that is to say (Fig. 9), the groins had to start from points F instead of from G, while the abutments of the transverse arches rested upon the imposts F, H, G, I. When it

was necessary then to close the vaults, the builders placed the planks bearing the masonry or earthen forms upon the extrados of these transverse arches and upon the two diagonal centres of timber.

In the architecture of all building nations, logical deductions follow one another with fatal severity. One step forward can never be the last, one must always go on; from the moment that a principle is the result of reasoning, it at once becomes its slave. Such is the spirit of the Western nations; it comes out as soon as the society of the Middle Ages begins to be conscious and to organize itself; it could not be checked, for the first man who founds a principle upon a course of reasoning cannot say to Reason, "Thou shalt go no farther." The builders, in the shadow of the cloisters, recognized this principle from the time of the eleventh century.

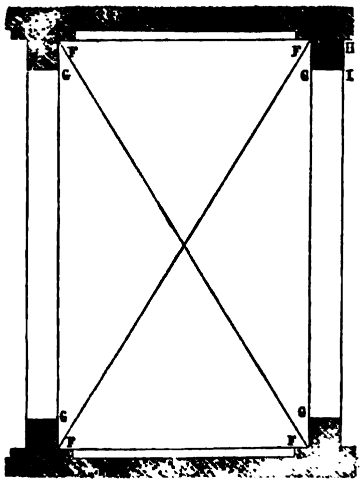


Fig. 9.

One hundred years later they were no longer the masters of it. Bishops, monks, nobles, commoners, had they wished, could not have prevented the Romanesque architects from producing the architecture termed *Gothic;* the latter was only the predestined consequence of the former. Those who pretend to see in Gothic architecture (entirely secular) anything else than the emancipation of a nation of artists and artisans, who, having been taught to reason, reason better than their masters, and with the forces put into their hands, carry them in spite of themselves very far from the goal that at first they wished to reach; those who believed that Gothic architecture is an

exception, a caprice of the human mind, have certainly not studied its principle, which is but the rigorous application of the system inaugurated by the Romanesque constructors. It will be easy for us to demonstrate it. Let us go on.

We see already, at the end of the eleventh century, the principle of the Roman groined vault laid aside.[1]

The transverse arches are definitely admitted as a vital force, elastic and free, a framework on which rests the vault proper. If the builders admitted that these permanent centres were useful transversely, they must likewise admit their usefulness longitudinally. No longer considering the vaults as a homogeneous, concrete crust, but as a series of *panels* with curved surfaces, free, and resting upon flexible arches, the rigidity of the lateral walls contrasted with the new system. It was necessary that these *panels* should be free in every direction; otherwise, the breaks and fractures would have been so much the more dangerous when these vaults were fixed upon flexible arches in one direction and upon rigid walls in the other. They stretched wall-arches from one pier to another, over the walls, longitudinally. These wall-arches are only transverse semi-arches, sunk partly in the walls, but not depending upon its construction. By this means the vaults rested solely upon the piers, and the walls became only enclosures, which, at need, could be built afterward or omitted. It required an impost for these wall-arches, a particular point of support, so the Romanesque builders added for this purpose a new member to their piers, and the groined vault took its start in the re-entering angle formed by the abutment of the transverse arch and that of the wall-arch, as indicated in Figure 10. *A* is the transverse arch, *B* the wall-arch, *C* the groin of the vault; the plan of the pier is in *D*, but if the pier was detached, if a nave was accompanied by aisles, it would take the form of Figure

[1] It is in the nave of the church at Vezelay that one must admit the abandonment of the Roman system. There the high, groined vaults, upon an oblong plan, are the intersection of ellipsoids, with projecting transverse arches and wall-arches.

10*b*. *A* is the transverse arch of the great vault, *B* the archivolts bearing upon the wall.

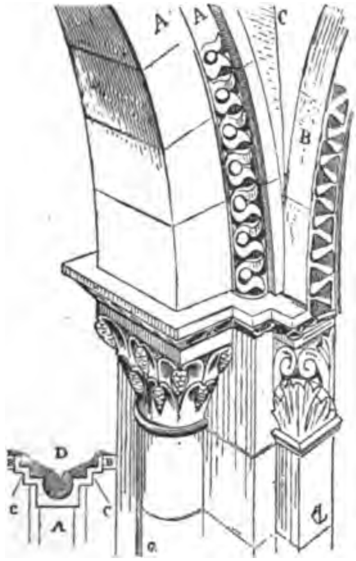


Fig. 10.

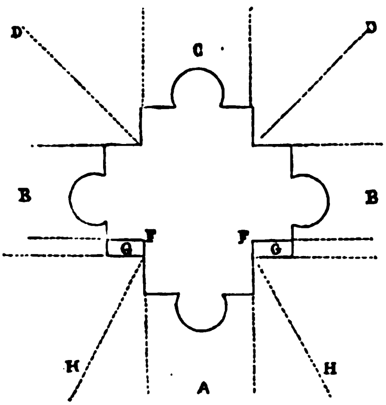


Fig. 10*b*.

Above these archivolts, this wall retreats in *F*, so as to allow the pilasters *G* to carry the higher wall-arches. *C* is the transverse arch of the aisles, *D* the groins of the vaults of this aisle, and *H* those of the high vaults. The vaults of the aisles are stretched over the transverse arches *C*, the extrados of the archivolts *B*, and upon a wall-arch partly sunk in the wall of the aisle, and resembling the higher wall-arches in Figure 10. Accordingly, then, the mouldings of the vaults at once give the horizontal section of the piers, and their form is derived from these mouldings.

Nevertheless, these vaults were insufficiently buttressed, and movements were seen in the piers; consequently, the principal sinews of the vaults, the transverse arches, were put out of shape. Not

knowing how to support the pressure, the builders occupied themselves at first in rendering the effect of this less disastrous. They had observed that the greater the section presented by the stones of an arch from the intrados to the extrados, the greater would be the disorder occasioned by the movement produced in that arch.

They were not the first who had recognized that law. The Romans, before them, when they had large arches to raise, had been careful to make them of several rows of voussoirs, concentric,

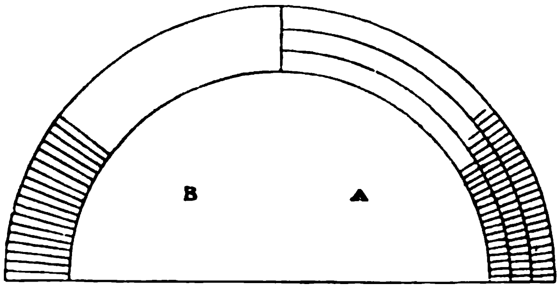


Fig. 11.

but independent of one another, as indicated by Figure 11 in *A*. The arches built in this way form, as it were, so many rings, acting separately and preserving much greater elasticity, and, therefore, greater resistance than in an arch of the same section, built after the method indicated in *B*.

The Romanesque builders, according to this principle, composed their transverse arches of two concentric rows of voussoirs; the one, that of the intrados, taking a longer section or portion of radius than that of the extrados, and, as the transverse arches were only permanent centres, designed to receive the ends of the planks on which they built the masonry of the vault, they allowed the second row of voussoirs to project beyond the first row sufficiently to support the ends of these planks.

Figure 12 explains this method. In *A* is the row of voussoirs on

the intrados; in *B*, that of the stones of the extrados with the two projections *C*, designed to receive the ends of the planks *D*, over which they built the masonry of the vaults.

The wall-arches, having a smaller diameter, and not being subject to the effects of the pressure, are composed of a single row of

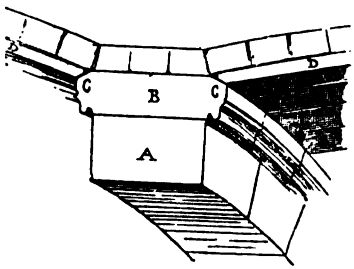


Fig. 12.

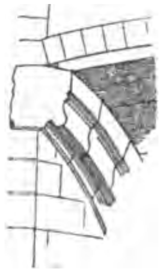


Fig. 12*a*.

voussoirs having, as Figure 12*a* shows, the projection necessary to hold the planks.

We now see that the Romanesque builders plainly exposed their means of construction; that, far from seeking to disguise them, they determined their architecture by those very means.

Does any one wish another proof of this fact?

The Romans terminated the tops of their columns by capitals, but the projection of the abacus of these capitals supported nothing; it was only an ornament.

Accordingly, when the Romans rested a groined vault upon columns, as frequently happened, for example, in the halls of the thermæ (hot baths), the abutment of the vault was in a vertical line with the body of the column (Fig. 13). And then a singular fact, for which no one can account, the shaft of the Roman column bore not only its capital, but the complete entablature of the order; so that, in point of fact, all the parts comprehended between *A* and *B* served no purpose, and the broad projections *B* could be used only to

support the wooden centres destined to close the vaults. It must be granted that this was a great luxury for an accessory object.

When the Romanesque builders place an arch upon a column, whether free or engaged, the capital is only a corbel destined to receive the abutment of the arch, a projection serving as a link between the cylindrical shaft of the column and the square impost of the abutment (Fig. 14). Then the capital is not only an ornament, but a useful member of the structure (see "*Chapiteau*").

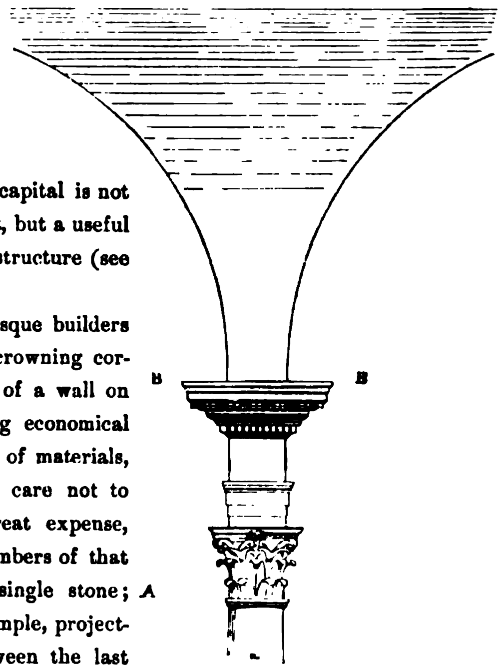


Fig. 13.

If the Romanesque builders had to place a crowning cornice at the top of a wall on the outside, being economical of the time and of materials, they took great care not to carve out, at great expense, the different members of that cornice from a single stone; they set, for example, projecting corbels between the last row of stones, and upon these corbels they placed a stone coping to serve as a drain for the roof (see "*Corniche*").

It is useless to insist further upon these details, which will present themselves in their place in the course of this work.

The construction of vaults, then, was the great object of the architects of the Middle Ages; they had arrived, as we have shown, at

combinations ingenious in themselves, although they had not yet found suitable means for firmly maintaining these vaults, and were reduced to expedients for them. Thus, for example, they filled in these vaults with tufa, or with light materials, in order to diminish the effects of thrust; they reduced them in thickness as much as possible; they filled in the masonry under the roof of the aisles in the line of the thrust, in the hope of preventing the deflection of the piers; they placed at the base of these buttresses transverse ties of wood, concealed by the slope of the roof, in order to unite the piers and the outer walls. These expedients sufficed in small constructions; in large ones they availed nothing but to mitigate the effects of the pressure, without completely destroying them.

Fig. 14.

We must take account of these effects in order to understand the series of reasonings and attempts by which the builders passed from ignorance to scientific knowledge.

Let (Fig. 15) be the cross-section of a Romanesque church at the end of the eleventh century, built, like that at Vezelay, with groined vaults over the aisles and over the central nave.

In *A*, the structure is represented as the architect had designed it; in *B*, as the pressure of the vaults had forced it out of shape. They had taken the precaution of leaving iron tie-bars *C D*, at the springing of the transverse arches; but these bars, probably poorly forged, had been broken. A century and a half after the construction of the nave, the effects produced had already caused the ruin of several vaults, and they had hastily built the exterior flying-buttresses *E*, indicated by dots upon our drawing.

These effects were: First, the bending of the piers and walls which bind them from *F* to *G*, the consequent sinking of the transverse

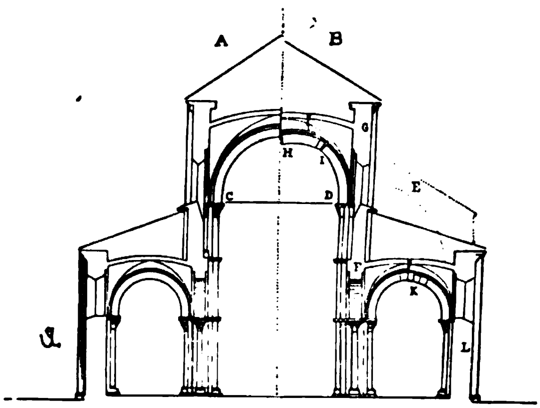


Fig. 15.

arches at *H* at the key and the crushing of the beds of the voussoirs forming the haunches of these arches, at *I* in the intrados; Secondly, the dislocation of the transverse arches *K*, of the aisles as indicated in our figure; and hence, again the bending of the exterior walls *L*, of the aisles. These effects were produced everywhere in the same manner. In studying them the builders thought, not without reason, since the fact is constant, that the whole evil was produced by the pressure of the semicircular arches and of the vaults that they partly support; that the too flat concavity of these vaults had an oblique

action, beyond the safety point; that the thrust of a semicircular arch increases in direct ratio with its action; that the dislocation undergone by these arches shows their weak points, viz., the key and the haunches; that at all times when a semicircular arch is not perfectly buttressed, and when the piers that support it diverge, these arches are thrown out of shape, as indicated in Figure 16.

Let this be a vault, the diameter of whose transverse arches is 7.00 metres, and the thickness of its voussoirs 0.60 c.; the walls have spread at the springing of the arches by 0.20 c. each; hence the diameter of the half-circle, whose centre is at B, has increased to

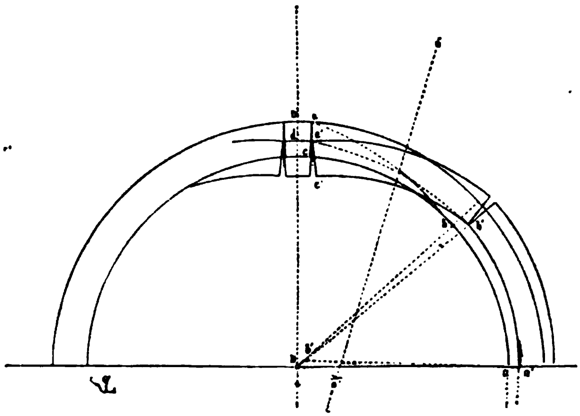


Fig. 16.

7.40 m., and the points a at the extremity of the transverse arches have receded to a'. The segment ab, which is a little less than a quarter of the half-circle takes the position a' b'; for, supposing that the pier breaks and turns upon a point placed at 3.00 m. below the spring of the arch, that extremity a' will descend below the level of the point a, and the centre B will rise to b'. The consequences of this first movement will be:

First, the fall of the key D to d, and the sinking of the segment b c to b' c'.

This effect will continue until the diagonal curve *b e* drawn from the intrados to the extrados of the segment, *b c*, shall be shorter than the distance between *b'* and *e'*. We should remark in passing, that the Romanesque vaults, which people suppose to have been built in elliptical form, have acquired that curve only through the divergence of the piers.

Forty centimetres of divergence between these piers, out of the vertical, give forty centimetres fall from the summit of the arch; and the difference between the radius of an arch, in this case, and the rise of the curve, is then 80 c.

CHAPTER IV.

ORIGIN OF THE POINTED ARCH.

THE builders could not but notice these effects, and seek means to prevent them. The first means they seem to have used are these: having a nave whose transverse arches were 7.00 m. in diameter at the intrados, and 0.60 c. thick as to their voussoirs, and having

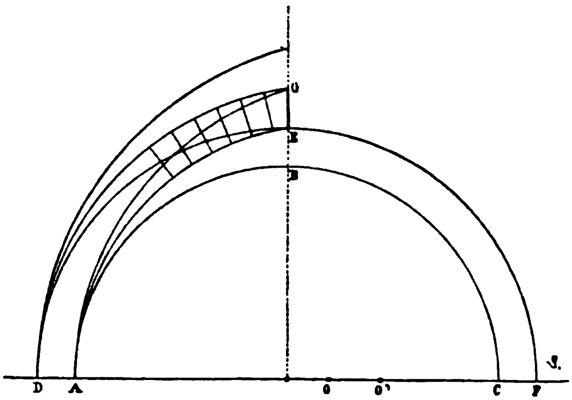


Fig. 17.

observed (Fig. 16) that the segment b' c' in sinking pressed the lower segment a' b' on the intrados at b', and the key at the extrados in e', they concluded that the curvilinear triangle b' e' c' was useless, and that the diagonal b' e' alone offered any resistance; then, starting

from this principle, they drew (Fig. 17) the two semicircles of the intrados and extrados *A B C*, and *D E F;* then upon the diameter *A C*, they sought the centre *O*, of an arc joining the point *A* on the intrados to the point *E*, on the extrados of the semicircle.

Placing a joint at *E G*, instead of a key-stone, in order to avoid the effect of equilibrium seen in Figure 16, they cut the voussoirs of this new arch *A E*, following the lines normal to the curve *A E*, that is to say, tending toward the centre *O*.

If fractures still occurred in these transverse arches, thus composed of two diagonal curves *A E*, the builders proceeded with that arch *A E* as with the semicircle — that is to say, they pushed the centre from *O* to *O'* upon the diameter in such a way as to obtain an arc joining the point *A* to *G*.

Thus, in the vaults of the twelfth century, we see little by little the transverse arches giving up the semicircular form to approach the pointed arch.

The best proof that we can give in support of our hypothesis, is the accurate list of a great number of these primitive, broken arches which have a rise longer than the radius, by exactly once, twice, or three times the thickness of their skewbacks. But this proof is evidence only to those who have been able to measure exactly a large number of transverse arches of that epoch. We give, then, a general observation which can be made by all the world, without recourse to measures difficult of access.

There are districts, like Ile-de-France, for example, where the Romanesque semicircular transverse arches have only a slight thickness of voussoirs. Now, here in the first vaults having pointed arches, the acuteness of these arches is scarcely perceptible, while in the provinces where the Romanesque semicircular transverse arches are very thick, as in Burgundy, the acuteness of the transverse arches, in the first vaults abandoning the semicircle, is much more marked.

The adoption of the pointed arch was so surely the result of the

observations which the builders had made upon the dislocation of the semicircular arches, namely, the displacement of the haunches and the sinking of the key-stone, that there exists a large number of transverse arches of the twelfth century drawn as indicated in Figure 18; that is to say, having four centres: two centres, *A*, for the portion of arcs *B C* and *D E*, and two centres, *G*, for the portions of arcs *C D*, comprehending the haunches, this being done in order to present from *C* to *D* a greater resistance to the effect of displacement felt between the points *C* and *D;* for the nearer the line *C D* comes to being a straight line, the less is it subject to breakage from within outward, and by this design the builders avoided giving the transverse arches an acuteness which could not fail to give a shock to those still accustomed to the semicircle.

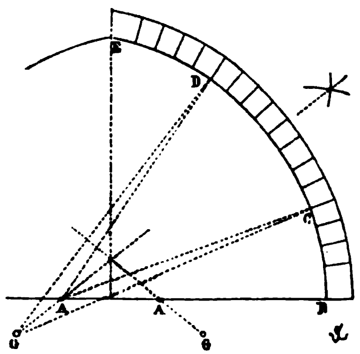


Fig. 18.

From the moment when the transverse arch formed by two circular arcs had replaced the semicircular, there flowed from this innovation a stream of consequences, which was to carry the builders very far beyond the goal which they expected to reach. The broken arch, or the pointed arch (since that is its true name), used as a means of construction, rendered necessary by the general structure of the large nave vaults, and obtained by observing the effects resulting from the thrust of semicircular arches, is a veritable revolution in the history of the art of building.

People say: "The builders of the Middle Ages, in adopting the pointed arch, have invented nothing; there are broken arches in the most ancient monuments of Greece and of Etruria. The section

of the Treasury of Atreus at Mycenæ gives a pointed arch, etc." This is true, but they always omit one sufficiently important fact: that the stones composing these arches are set corbelwise, and that their beds are not normal to the curve, but horizontal. This is less than nothing to those who take account only of the outer form, but for us practitioners this detail, nevertheless, has its importance. And furthermore, if the Greeks and Romans had made vaults produced by broken arcs, what would that matter if the general principle of the construction be not derived from the combination of these curves and from the observation of their oblique effects?

It is evident that, from the day when man invented the compass and the means of describing circles, he has discovered the broken arch; and of what consequence is it to us if he did not establish a complete system upon the observation of the properties of these arches? Some, on the other hand, have been pleased to see, in the use of the pointed arch for the construction of vaults, a symbolical or mystical idea; they have pretended to demonstrate that these arches had a deeper religious meaning than the semicircular arch. But men were quite as religious at the beginning of the twelfth century as at the end, if not more so, and the pointed arch appears at precisely the moment when the spirit of analysis, or the study of the exact sciences and of philosophy, began to spring up in the midst of a society up to that time almost theocratic.

The pointed arch and its widespread consequences in construction appear in our monuments when the art of architecture is practised by the laity, and comes out of the seclusion of the cloisters, where, until this time, it had been exclusively cultivated.

The last Romanesque builders, those who, after so many attempts, had finally dismissed the semicircle, are not visionaries; they do not reason upon the mystical meaning of a curve; they do not know if the pointed arch is more *religious* than the semicircular arch; they build — a more difficult task than idle dreaming.

These constructors have to sustain large and high vaults upon

isolated piers; they tremble whenever they strike a centre; from day to day they remedy defects as they appear. They observe with disquietude the divergence, the least effect produced, and this observation is a constant and fertile source of instruction. They have only vague, incomplete traditions, and obscurity about them, and the monuments that they build are their only model. It is upon these that they make experiments; they have recourse only to themselves, and refer only to their personal observations.

When we study carefully the constructions raised at the beginning of the twelfth century, when we come to classify them chronologically, and follow the progress of the principal schools of builders in France, Burgundy, Normandy and Champagne, we are still seized to-day by that species of fever that possessed these constructors; we share their anxiety, their haste, to arrive at a sure result; we recognize their advances from one structure to another; we applaud their perseverance, the justice of their reasoning, the evolution of their knowledge, so limited at first, so profound soon afterwards. In truth, such a study is useful to us, builders of the nineteenth century, who are disposed to take the appearance for the reality, and who often substitute vulgarity for good sense.

Already, at the beginning of the twelfth century, the pointed arch was adopted for the large cradle-vaults in a part of Burgundy, in Ile-de-France and in Champagne; that is to say, in the provinces which were the most advanced and most active, if not the richest.

The naves of the churches of Beaune, of Saulieu, of Charité-sur-Loire, of the Cathedral of Autun, are covered by cradle-vaults formed by two intersecting, circular arcs, although, even in these structures, the archivolts of the doors and windows remain full-centre. It is a necessity of construction which imposes the divided arch upon these edifices, and not an individual taste; for (a remarkable fact) all the architectural details of these monuments reproduce certain antique forms borrowed from the Gallo-Roman edifices of the Province. Thanks to that innovation of the divided arch

applied to cradle-vaults, these churches have remained standing until our day, not, however, without having suffered disturbances grave enough to necessitate, two centuries later, the use of new means suitable to prevent their ruin.

But the edifices in which one grasps the transition from the Romanesque system of construction to that known as Gothic, is the porch of the church at Vezelay. This porch is in itself alone a monument, consisting of a nave in three divisions with aisles and vaulted gallery above.

The plan of this porch, built about 1130[1] is entirely Romanesque, and does not differ from that of the nave, built thirty years earlier; but its cross-section presents notable differences from that of the nave.

Already, toward the end of the eleventh century, the constructors of the nave of the church of Vezelay had taken a great step in replacing the high vaults, hitherto cradle-shaped, by groined vaults; but these vaults built upon an oblong plan, and produced by transverse arches and semicircular wall-arches, show us the gropings, the uncertainty, and the inexperience of the constructors (see "*Architecture Religieuse*" Fig. 21). In the porch, all the arches are pointed, the vaults are groined without projecting diagonal arches, and constructed of plastered, rough stones; the high vaults are very skilfully buttressed by those of the galleries of the first story. This ensemble presents a perfect stability.

We give (Fig. 19) the cross-section of the porch of Vezelay: the vaults of the galleries are produced by the wall-arches *A*, of the great vaults, which are true archivolts, and by the wall-arches *B*, whose origin is much lower down; hence the slope *A B* of the keystones of the lateral vaults, which form a continuous buttress enclosing the large vaults.

[1] It must here be said that the Burgundian architecture was at least twenty-five years behind that of Ile-de-France; but transitional monuments in Ile-de-France are wanting. The Church of Saint-Denis, built about 1140, is already almost Gothic as to its construction, and the intermediate edifices between that and those plainly Romanesque no longer exist, or have been almost entirely modified in the thirteenth century.

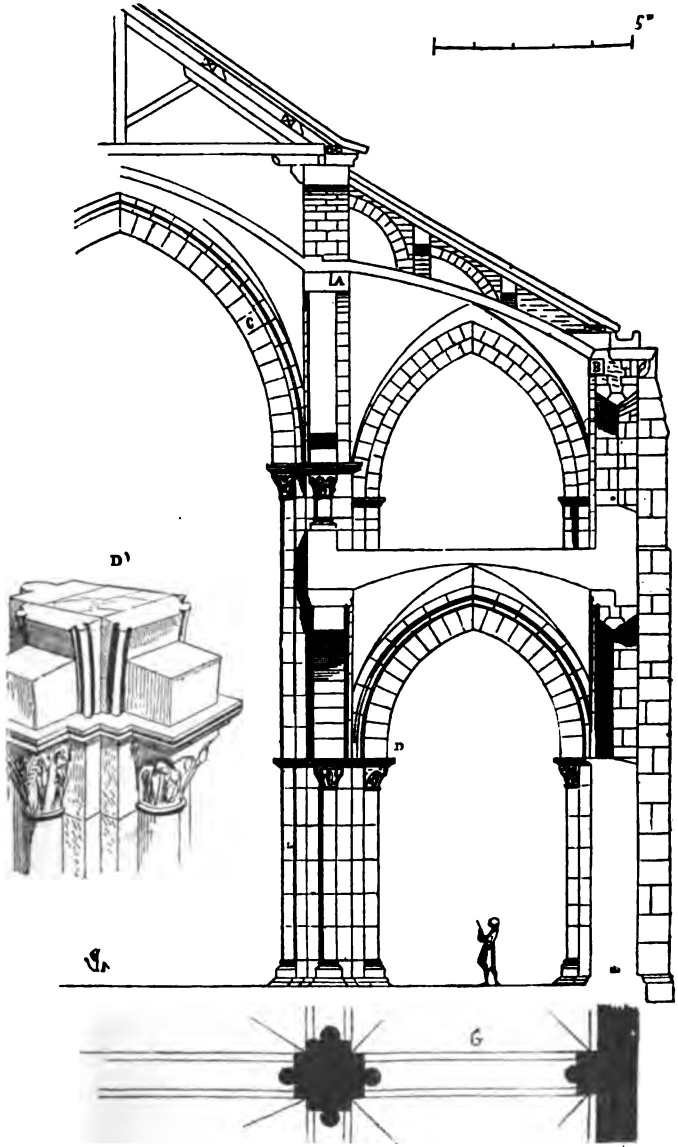


Fig. 19.

The bays were oblong, and the wall-arches starting on the same level as the transverse arches *C*, the key-stone of these wall-arches *A* is on a lower plane than the keys of these transverse arches; the great vaults, in consequence of this arrangement, are very much elevated while their projecting groins are barely perceptible.

In *D'* we have represented the detail of the skewbacks of the arches at the level *D* of the pier, and in *G* the ground plan, with the starting point of the arches and groins of the vaults.

This construction of vaults resembles in no respect the Roman construction; already the principle of independence between the different parts of building is conceded and developed.

Nevertheless, these vaults of the porch of Vezelay, except two, are not provided with visible ribs. They are held in place only by the adhesion of the mortar, and form each a homogeneous, concrete cavity like the Roman vaults. The only two vaults of this porch possessing such ribs could do without them; these are only a decoration, and do not really support the filling of rough stones. But there is in that an attempt which soon had important consequences.

The builders had already obtained, by means of the transverse arches and wall-arches, independent and resistant for each vault, a sort of elastic frame upon which, if any disturbance occurred, these vaults could move independently of one another. They wished to go farther: they wished the concave triangles of these vaults to be themselves independent of each other: and to do this, they composed the vaults of two quite distinct elements: the arches and the fillings; the arches considered as permanent, elastic centres, and the fillings as neutral concavities designed to close up the empty triangles left between these arches.

They began by avoiding a preliminary difficulty which had hitherto always bothered architects; they returned to the vault on a square plan, consisting of two oblong divisions, if necessity demanded it. In other words, they designed their vaults in a horizontal section, as indicated in Figure 20.

Let $A\ B\ C\ D$, be a square, perfect or nearly so, it matters little, containing two divisions of naves $A\ E\ B\ F$ and $E\ C\ F\ D$; the diagonals $A\ D$ and $B\ C$ are those which produce the vault; and these two diagonals are the diameters of two perfect semicircles, represented in the plan; these two semicircles, being of the same diameter, necessarily meet at the point G, which is the crowning key-stone. Taking a distance equal to the radius $G\ A$, and moving this radius around to the perpendicular $G\ I$, we have described the pointed-arch $E\ I\ F$ in such a way that the point I falls on the point G; this is the transverse arch whose horizontal projection is in $E\ F$.

Taking a line shorter than the radius $G\ A$, but greater than one-half $A\ B$, the width of the nave, and moving it around upon the perpendicular $H\ K$, we have described the pointed arch $A\ K\ B$; this is the transverse arch whose horizontal projection is in $A\ B$ or $C\ D$.

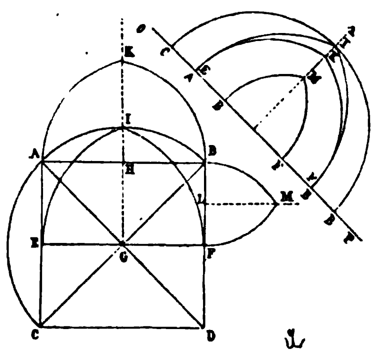


Fig. 20. Fig. 20*b*.

Finally, taking a line $L\ M$ shorter than the line $H\ K$ and longer than one-half of the line $B\ F$, we have traced the pointed arch $B\ M\ F$, which is the wall-arch, whose horizontal projection is in $B\ F$, $F\ D$, etc.

Cutting wooden centerings in accordance with these four curves laid out, upon the same line $O\ P$ (Fig. 20*b*), we fix the arches in stone on the extrados of these centerings, and we have obtained the framework of the vault represented by Figure 21.

These are the original Gothic vaults so-called. It will be noticed that these vaults are produced by a semicircle, which in the first place furnishes the diagonals; it is the semicircle which governs the height of the pointed arches.

The real ogival arches, it may be said in passing (for thus the diagonal arches are named), are, then, full-centered, which indicates clearly enough that the word *ogival* is not appropriate for the

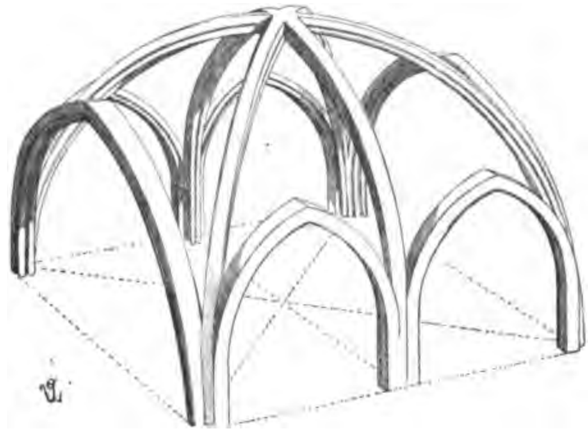


Fig. 21.

broken arch. But this is not the moment to discuss these words (see "*Ogive*"), and our remark is made here only to point out one of the numerous errors upon which people rely, to judge of an art with which they are but slightly acquainted.

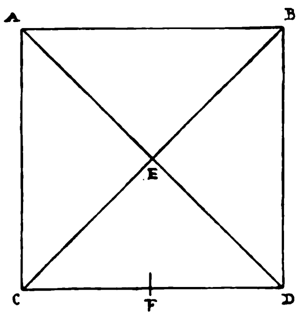


Fig. 22.

The broken arch had been adopted by the last Romanesque architects, as we have seen above, to lessen the effects of the thrusts. Now its function increases, and it becomes a practical means of closing vaults whose real generator is the semicircular arch.

When (Fig. 22) a groined vault is formed by two semi-cylinders at right angles, the arches *A B*, *C D*, *A C* and *B D* are semicircular,

and their intersections *A D* and *B C* are elliptical, since the key *E* does not rise above the level of the key *F*, while the diameters *A D* and *B C* are longer than the diameters of the semicircles *A B* and *C D*.

This brings no danger if the vault *A B*, *C D* is homogeneous and concrete; if it forms a crust in one piece like the Roman vaults.

But if the builder wishes to preserve in the triangles of his vaults a certain elasticity, if he wishes to give sinews to the diagonal groins *A D* and *B C*, if he wishes to have the triangles *A B E*, *C D E*, *A C E* and *B D E* rest upon these sinews as upon permanent centerings and if this vault has a great extent — then one perceives that it would be imprudent to draw the diagonal arches *A D* and *B C*, which fulfil so important a function, upon a curve which should not be at least a semicircle.

If this design is not absolutely contrary to good construction, it presents, at least, difficulties of execution, either in finding the points through which these elliptical curves must pass, or in shaping the voussoirs. The semicircular arch avoids these difficulties, and is incomparably more solid.

The first builders of purely Gothic vaults do something very simple in appearance; instead of describing the semicircle upon the diameter *A B* like the Romanesque builders, they describe it upon the diameter *A D*. There in reality is their only innovation, and in adopting it they suspect nothing, we believe, of the consequences of an act apparently so natural. But in the builder's art, essentially logical, and based on reasoning, the least deviation from the established methods rapidly brings necessary and rigorous consequences, which carry us far from the point of departure.

It must be said that the first Gothic builders, repelled not unreasonably by the attempts of the Romanesque builders, who generally arrived at deceptive conclusions, were not alarmed by the results of their new methods, but on the contrary sought, with rare sagacity, to profit by all the resources offered to them by these methods.

The Gothic builders had not discovered the broken arch; it existed, as we have seen above, in the constructions whose system was perfectly Romanesque.

But the Gothic architects applied the broken arch to a system of construction of which they were indeed the true and only inventors.

There were broken arches, in the twelfth century, in all Western Europe. There is no Gothic construction of that epoch except in France and upon a small part of its present territory, whatever they may think who do not admit that anything was invented among us before the sixteenth century.

It is with the broken arch as with all human inventions, which are in a latent state long before receiving their true application.

Gunpowder was invented in the thirteenth century, but it was not really used until the fifteenth, because the time had then arrived when that agent of destruction found its necessary application.

It is the same with printing; at all times men had made stamps, but the idea of joining letters of wood or of metal and printing books came only when many people knew how to read, and when instruction and knowledge were spreading among all classes and were no longer the privilege of a few monks shut up in their cloisters.

Leonardo da Vinci, and perhaps others before him, had foreseen that steam would become a motive power very easy to use; still, men have made steam engines only in our time, because the moment had arrived when that agent, by its power, was alone capable of satisfying the needs of our industry and our activity.

It is, then, childish to say that since the broken arch belongs to all times, the builders of the twelfth century can lay no claim to its invention. Certainly, they did not discover it, but they made use of the resources that it presents by virtue of its properties, in building; and, we repeat, it is only in France — that is to say, in the royal domain and several neighboring provinces — that they knew how to apply it in the art of building, not as a form chosen

by caprice, but as a means of extending a principle whose serious and useful consequences we are about to make known.

If, in adopting the semicircular arch for the diagonals of vaults, the builders at the end of the twelfth century had wished to apply it to transverse and wall arches, they would in the beginning have taken a step backward, since their predecessors had adopted the pointed arch, in consequence of unfortunate experiments, as having less thrust than the semicircular arch; and then they would have found themselves greatly embarrassed about closing their vaults.

In fact, the keys of transverse arches and of wall arches described upon a semicircle would be found so much below the level of the keys of the ogival arches that it would have been difficult to close up the filling with stones, and that, had they closed them, the appearance of these vaults would have been very disagreeable, and their thrust considerable, since it would have been caused by, first, the transverse semicircular arches, and then by the enormous weight that the stone filling would have added.

On the contrary, the advantage of the tierce-point arch adopted for the transverse arches, in the vaults with ogival arches, is not only that it has a very slight thrust by itself, but also that it reduces a great part of the weight of the stone filling, or rather, renders the pressure of that weight almost vertical.

In fact, let Figure 23 be the plan of a vault with ogival arches; if the arches *A D* and *C B* are semicircular, and if the transverse arches *A B* and *C D* are also semicircular, the representation in elevation of these arches will give, for the ogival arches the semicircle *E F G*, and for the transverse arches the semicircle *E H I*.

In this case the stone filling of the triangle *C O D* will weigh upon the circular arc *K H L*; in other words, about three-fifths of the semicircle. But if the transverse arches are drawn according to the broken arc *E M I*, the stone filling of the triangle *C O D* will weight only the portion of that arc comprehended between *P M R*, the points *P* and *R* being given by a tangent *S T* parallel to the

tangent VX, and the portions of the filling included between $E\,R$ and $I\,P$ will act vertically.

If the transverse arches are semicircles, the oblique weight of each triangle of filling-stones will be $O\,N\,Q\,Q'\,N'$; while if they are

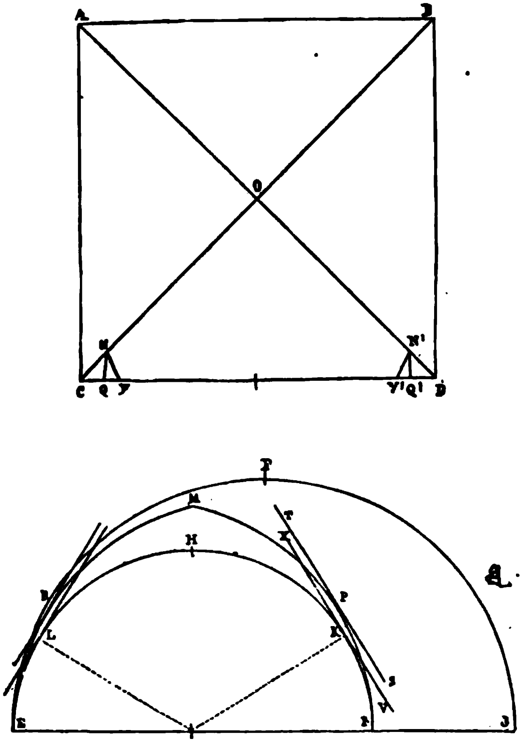


Fig. 23.

drawn in tierce-point, that weight will be only $O\,N\,Y\,Y'\,N'$. The experimental method sufficed to give these results, and at the end of the twelfth century the builders had no other. It is our work to demonstrate the exactitude of that method.

We have just said that the point K, where the weight of the filling begins, gives an arc $I\ K$, which is about one-fifth of the semicircle. Now (Fig. 24) let $A\ B$ be a quarter of a circle, $O\ C$ a line drawn at 45 degrees dividing this quarter of a circle into equal parts; voussoirs placed from C to B, if not supported by the pressure of other voussoirs placed from B to D, will sway, according to the laws of gravity, and consequently push against the voussoirs set from A to C.

So it is at C that the rupture in the arch must take place; but account must be taken of the friction of the surfaces of the voussoir

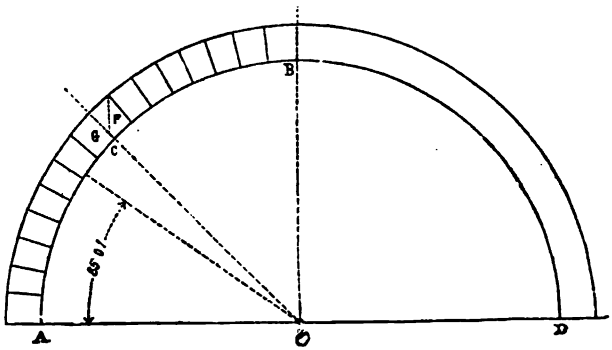


Fig. 24.

beds, and of the adhesion of the mortar. This friction and adhesion are still enough to maintain the voussoir F in its place and unite it firmly to the lower voussoir G.

But the voussoir F, sharing in the weight of the voussoirs set from F to B, carries along with it the voussoir G, and sometimes one or two below it as far as the point where the sections of the voussoirs give an angle of 35 degrees, which is a little less than a fifth of the semicircle.

It is only above this point that the rupture takes place, when it must occur (see Fig. 16) and consequently that the actual weight begins.

Whether the calculation be theoretical or practical, it is certain

that the builders of the twelfth century counted upon some time reducing the thrusts of the vaults enough to do without buttresses, and to maintain the vaults upon piers of moderate thickness, provided they were weighted; for they did not think at first, that it was necessary to oppose flying-buttresses to the thrust that they believed themselves to have almost annulled, whether by the obliquity of the ogival arches, or by the broken curve of the transverse arches. Still, experience showed them that they were mistaken. The resultant of the oblique thrusts of the semicircular ogival arches, added to the thrust of the transverse arches in tierce-point, was strong enough to overturn piers which were very high above the ground and were only a collection of uprights without breadth of base. So they set flying-buttresses, at first only on a level with the points of junction A of the three arches (Fig. 25) and dispensed with them at the height of the points B, receiving the detached transverse arches. But to what level carry the tops of these flying-buttresses? There lay a difficulty so much the greater, since theoretical calculation gives no certainty on this point, and long experience alone can show it. As far as we can judge by the small number of primitive flying buttresses preserved, the following is the method followed by the architects.

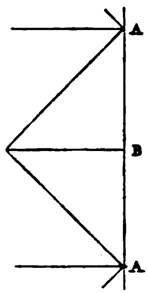


Fig. 25.

Let (Fig. 26) A B C, be the transverse arch separating the great vaults, and from the point D, the centre of the arch A B, let a line D E be drawn, making an angle of 35° 0′ with the horizon; let F G be a tangent at the point H; let A I be the thickness of the wall or of the pier; then the tangent F G will meet the exterior line I K of the pier at the point L.

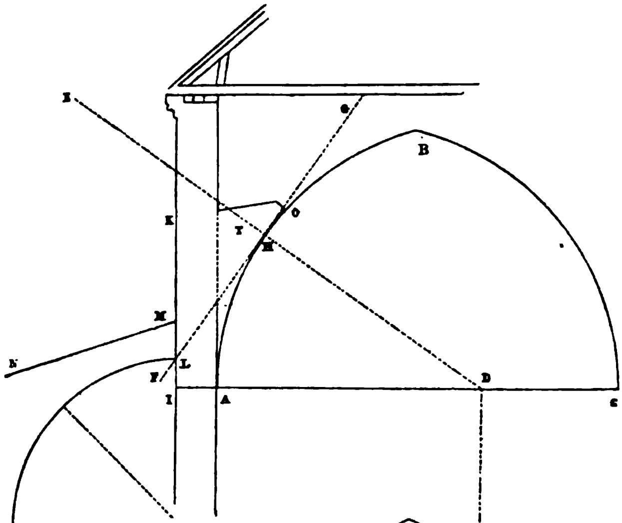
This is the point that gives the intrados of the highest voussoirs of the flying-buttress.

That arch is then a quarter of a circle or a little less, its centre

being placed upon the prolongation of the line *K I* or a little inside of that line.

The load *M N*, put upon the flying-buttresses is fixed arbitrarily at first, slight at the summit *M*, strong above the abutment *N*, which

Fig. 26.



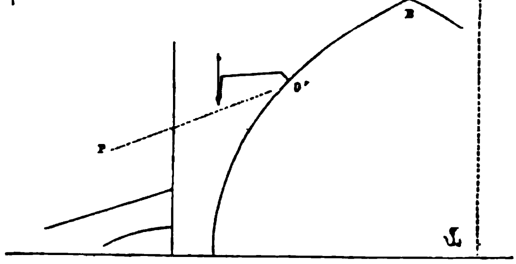


Fig. 26b.

gives a slightly perceptible inclination to the line *N M* of the coping.

Soon certain effects manifested themselves in these constructions, because of the thrust of the vaults and in spite of these flying-buttresses. The reason is this: behind the haunches of the arches and

vaults at T they filled-in with masses of rubble-work, as much to load the piers as to maintain the haunches of the arches and their filling. These masses had, in fact, the advantage of hindering the arches from breaking at the point H; but the whole weight of the filling, acting from K to O, and that weight being considerable, there resulted a slight displacement of the key-stone B, the arch not being weighted from O to B, and in consequence a change of form, as indicated (Figure 26*b*).

This change of form produced a break at the point O', the upper level of the masonry, and hence a very oblique thrust $O' P$, above the summit of the flying-buttresses. Therefore the equilibrium was broken. Accordingly, it was necessary to rebuild all the flying-buttresses in the early Gothic monuments, some years after their construction; and then they either contented themselves with raising the summit of these buttress-arches, or they doubled them by a second arch (see "*Arc-Boutant*").

We do not gloss over the false moves of these constructors; but, like all those who enter a new field, they could reach the goal only after groping. It is easy to-day, when we have monuments built with skill and care, like the cathedral of Amiens or that of Rheims, to criticise the attempts of the architects at the end of the twelfth century. But at that epoch, when they possessed only Romanesque monuments, small and badly enough built, when the exact sciences were scarcely known, the new task that the architects imposed upon themselves bristled with ever-recurring difficulties, which they could conquer only by a series of observations made with the greatest care.

These are the observations which trained the skilful constructors of the thirteenth and fourteenth centuries.

CHAPTER V.

Development of Principles.

IT must be said to the credit of the architects of the twelfth century, that, having adopted a new and unprecedented system of building, they pursued its development with a rare tenacity and perseverance, without one backward glance, despite the obstacles and difficulties which arose at every attempt. Their tenacity is all the more honorable, since they could not foresee in adopting the system of construction of the Gothic vaults, the results which came naturally from this system. They acted like men moved by strong conviction; they opened for their successors a broad and sure path in which Western Europe walked without hindrance for three centuries.

Every human conception is tainted with some error, and the truly immutable, in everything, is still to be found; each discovery carries within it, at its birth, the cause of its downfall, and man has no sooner admitted a principle than he recognizes its imperfection, its flaws, and his efforts tend to combat the defects inherent in this principle.

Now, of all human conceptions, the construction of buildings is one of those which are confronted by the most serious difficulties, in that they are of opposite natures, some material, others moral. In fact, the constructor must not only seek to give to the materials used the most suitable form, according to their own nature, but he

must group them in such a way as to resist diverse forces and foreign agencies. But in addition he is obliged to submit himself to the means at his disposal, to satisfy moral needs, to conform to the tastes and customs of those for whom he builds. There are the difficulties of conception, the efforts of the artist's intellect; there are also the means of execution from which the builder knows not how to free himself.

During all the Romanesque period the architects had made vain attempts to reconcile two principles seemingly irreconcilable; namely, the tenuity of vertical supports or the economy of material together with the use of the Roman vault with more or less alteration. Some provinces had, by reason of influences foreign to the Western spirit, adopted the pure Byzantine construction.

At Périgueux they built, at the end of the tenth century, the Church of Saint-Front, and from that isolated example rose a school. But it must be recognized that this kind of building was foreign to the new spirit of Western nations, and the constructors of Saint-Front of Périgueux erected that church as moulders might do, reproducing forms whose structure they did not comprehend. Thus, for example, the pendentives which support the cupolas of Saint-Front are faced by means of courses of stones set in corbels, whose beds are not normal to the curve, but horizontal; if these pendentives do not fall inwards, it is because they are held by the mortar, and adhere to the masonry which gives them their concave form.

In such buildings one sees only an attempt to reproduce forms whose geometrical reason the builders do not understand.

Moreover, we see complete ignorance, pitiable expedients applied as makeshifts at the moment when the difficulty presents itself, but no foresight.

A great number of Romanesque constructions indicate, upon the part of the architects, a complete want of foresight. One structure is begun in the vague idea of ending it in a certain fashion, and stops half-way, because the builder does not know how to solve the

problems which he has set before himself; another can be finished only by the use of means clearly foreign to its first conception. We see that the early Romanesque constructors built from day to day, relying upon inspiration, upon chance, upon circumstances, perhaps they were even counting upon a miracle to perfect their work.

The legends attached to the building of great edifices (even if the structures were not there to show us the embarrassment of the architects), are full of dreams, during which the architects see some angel or some saint, taking the trouble to show them how they ought to build their vaults, or maintain their pillars; which did not always prevent these monuments from collapsing soon after their completion, for faith is not sufficient for building.

Without, perhaps, being less devout, the architects at the end of the twelfth century — chiefly, if not entirely, laymen — thought it prudent in the matter of building, not to wait for the intervention of an angel or a saint in order to erect an edifice. Moreover (a curious and noteworthy fact), the monkish chronicles, legends and histories which are so prodigal of praises of monuments raised during the Romanesque period, and which enlarge so complacently upon the beauty of their structure, their grandeur and their decorations, although many of these monuments are only wretched buildings of rough stones, badly designed and worse executed, become abruptly silent at the end of the twelfth century, when architecture passes from the cloisters into the hands of the laity. Perchance there is a word about the edifice — a phrase, dry and laconic; but as to the masters of the work, nothing.

Is it credible, for example, that, in the voluminous records of the church of Nôtre Dame at Paris which contains documents dating back to the twelfth century, not a single word is said about the construction of the present cathedral?

Laborious and intelligent artists, sprung from the people, you, who have been the first to free yourselves from worn-out traditions; who have entered freely into practical science; who have

formed that army of skilful workmen soon to spread over the whole surface of the Western continent; who have opened the way for progress, for bold innovations; who in short, belong, by so many titles to modern civilization; who were the first to possess its spirit of research, its craving for knowledge; if your contemporaries have let your names be forgotten: if, despising the efforts by which they profit, those who claim to direct the arts of our time attempt to disparage your works, then, at least, among so much injustice past and present, let our voice be raised to vindicate the place which belongs to you, and which your modesty has made you lose. If, less engrossed with your labors, you had, like your confrères in Italy, boasted of your knowledge and glorified your own genius, we should not to-day be forced to search your works in order to bring to light the profound experience that you had acquired, the practical means that you had so judiciously calculated, and above all to defend you against those who are incapable of understanding that genius can be developed in the shade,—that by its very nature it seeks silence and obscurity;—against the many who judge on the strength of sentences pronounced by passion, or self-interest, and not after their own examination.

It must, however, be said that to-day, it is no longer permissible to decide questions of history touching the arts, politics, or letters, by simple affirmations or negations.

And the retrograde minds are those that wish to judge these questions, in relying upon the antique methods or upon their own partiality. No sensible artist dares to maintain that we ought to build our churches and houses as they did in the twelfth or thirteenth century, but no just mind would be unable to comprehend that the experience gained by the masters of that time can be more useful to us, according as they made greater innovations. The most difficult obstacle for us to get rid of, the real, vital obstacle, is, we must admit, intellectual laziness; each man wishes to know without the trouble of learning, and each man pretends to judge without

knowing the proofs of the case; and the truest, best written, and most useful principles will be set aside among obsolete relics, because some man of wit has derided them, and because the listening crowd is too happy to applaud a criticism which saves them the trouble of learning. A sad glory, after all, that of prolonging the duration of obscurity; it can bring no profit to its possessor in a century which boasts of casting light upon all things; whose activity is so great that, being unable to find in the present sufficient food for its intellectual needs, it wishes again to unfold the past before itself.

If our French architecture of the Renaissance is superior, in the eyes of persons who have carefully studied it and have brought into that study an enlightened criticism, to the Italian architecture of the fifteenth and sixteenth centuries, does not this come from the fact that our Gothic schools, despite the abuses of later times had long since trained skilful professionals and intelligent workmen, knowing how to submit form to reason; and from the fact that these schools were specially adapted to liberate the minds of the architects and workmen, and to familiarize them with the numerous difficulties which surround the builders?

We know that this language is unintelligible to those who judge the different forms of our art after their own sentiments or prejudices; and therefore, it is not to those people that we address ourselves, but to those architects who have long been familiar with the resources and difficulties presented in the practice of our art. Indeed, for artists, the study of an art where everything is foreseen and calculated, which even sins by an excess of research and of practical means, in which matter is both superior to form and submissive to principle, cannot fail to develop the mind and prepare it for the innovations that our time demands.

It would be a digression from our subject to explain how, at the end of the twelfth century, there was formed a powerful lay school of builders; how that school, protected by the Episcopate, which

wished to lessen the importance of religious orders, and possessing the sympathies of the people whence it came and whose spirit of research and progress it reflected; and having been welcomed by secular feudalism, which did not find among the monks all the elements which it needed for building its dwellings: how that school, we repeat, profiting by these favorable circumstances, gained a strong foothold, and, consequently, great independence. It will suffice us to indicate that state of things, new in the history of the arts, to make its consequences appreciated.

We have previously seen where the builders had arrived about 1160, and how they had been led to modify successively the Romanesque vault, which was only a degraded condition of the Roman vault, and to invent the Gothic vault proper. This great step taken, there still remained much to be done. The first result of that innovation was to force the builders to design their edifices, beginning at the vault, and hence to leave nothing to chance, as had happened only too often with their predecessors. This method, strange in appearance, which consisted in deriving the ground-plan from the design of the vault, is eminently rational. What do we wish when we build a vaulted edifice? To cover a surface. What is the end that we propose to attain? To fix vaults upon points of support. What is the principal object? The vault. The points of support are only means.

The Roman builders had already been led to derive the plan of their vaulted edifices from the form and extent of these same vaults; but this principle was only a general principle, and, from the examination of a ground-plan of the later Roman empire, one could not always conclude that such a part was vaulted in cradle-form, in groins or spherically, since each of these vaults might be in many cases, placed indifferently over these ground-plans.

It is no longer thus in the twelfth century; not only does the horizontal plan indicate the number and form of the vaults, but also their different members, transverse arches, wall-arches and diagonal arches,

and these members govern, in their turn, the arrangement of the vertical supports, their relative height and their diameter. Hence it should be concluded that, in order to draw definitely a ground-plan, and to proceed to its execution, it is necessary, first of all, to make the drawing of the vaults, of their slopes and of their abutments, and to ascertain exactly the dimensions and shapes of the stones of the various arches. The first Gothic builders acquainted themselves so promptly with that method of taking every construction at the top in order to arrive successively at the drawing of the bases, that they adopted it even in the edifices not vaulted, but having plank or timber ceilings, and they found themselves none the worse off, as we shall see later on.

The first condition in order to arrange the plan of an edifice, at the end of the twelfth century, was to know whether it was to be vaulted, and in what way. It is necessary, then, as soon as the number and directions of the arches of these vaults are known, to obtain the drawing of the abutments upon the capitals, for it will be the drawing of these abutments which will give the shape and dimensions of the abacus and capitals, as well as the number, size and position of the vertical supports.

Let us suppose, then (Fig. 27), a hall which is to be vaulted, having a length of twelve metres inside the building, and divided into compartments of six metres from axis to axis.

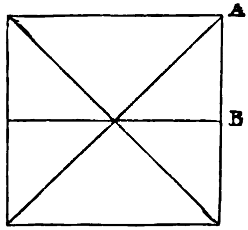


Fig. 27.

Let us adopt the system of diagonal arched vaults crossed by a transverse arch, after the method of the builders at the end of the twelfth century. We must trace the lower bed of the abutments of the arches falling on *A* and *B*, and find out the size of the voussoirs. We admit that these voussoirs, for a hall of such extent, must have 0.40 centimetres of width and height; we recognize that at that epoch the different arches of

a vault are almost always formed of voussoirs alike in dimensions and form. We recognize again that, since the wall-arches begin much higher up than the transverse and the diagonal arches, the slender columns serving to support them often rise above the level of the abutments of the diagonal and transverse arches; that, in outlining the bed of the abutments of the transverse and diagonal arches, we ought to take account of the elevation of the column supporting the wall-arch, just as we would take account of the wall-arch itself.

Let Figure 28 be the detail of the horizontal drawing of the terminus of the arches at *B;* from this point there rise only one transverse arch and two wall-arches. The latter are the commanding arches, for the transverse arch diverges from these wall-arches at their origin. Let *A B* be the surface of the wall; the wall-arch has a projection, usually, half as thick as the pointed arch or the transverse arch when these two arches have a similar section, and half as thick as the diagonal arch when that and the transverse arch have different sections. In the present case, the wall-arch has then 0.20 centimetres of projection from the surface of the wall. Through *C* we draw a line parallel to *A B.* The axis of the transverse arch being *D E,* and the points *F* and *G* being taken at 0.20 centimetres each from that axis, we draw the two parallels *F I* and *G K*, which gives us the thickness of the transverse arch. From *F* to *I'*, measuring 0.40 centimetres, we have its height between the intrados and extrados; we can then in the square *F I' K' G* trace the proper contour; it is the lower bed of the abutment.

Either the column supporting the wall-arch rises above the level of this bed, as indicated in *L*, or the wall-arch, as sometimes happens as in the Church of Nesle, Oise, takes its start upon the capital supporting the transverse arch; and then, from the axis *D E*, measuring off 0.40 centimetres on the line *A B*, which gives us the point *M*, we inscribe the contour of the wall-arch in the parallelogram *E O N M.* It is understood that this wall-arch should enter the

wall for several centimetres. The lower bed of the abutment being thus found, the abacus of the capital must be drawn, and its contour must form a projection around the ends of the arches. If the wall-arch is resting upon a column rising to its abutment, as represented in *L*, the abacus *P R S* turns squarely about and ceases at the column *L* of the wall-arch. If, on the contrary, the contour of the wall-arch descends as far as the capital of the transverse arch the abacus takes upon the horizontal plan, the form *P T V X*.

In order to draw the column under the capital, in the first case, from the vertex of the right angle *R* of the abacus we draw a line at 45 degrees; that line meets the axis *D E* in a point 0, which is the centre of the column, to which we give a diameter such that the projection of the abacus over the surface of that column shall be greater than the radius of the column. There remains then, between the column and the surface *A B* of the wall, a vacant place that we fill with a pilaster hidden by that column and the pillar of the wall-arch.

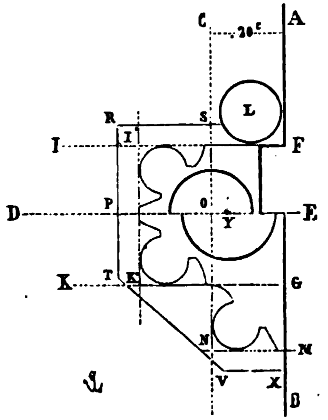


Fig. 28.

In order to outline the column under the capital, in the second case, we take a centre *Y* upon the axis *D E*, in such a way that the projection of the abacus over the surface of the column shall be greater than its radius; then the capital forms a corbel or bracket, and is found to be broader under the wall-arch than under the face of the transverse arch.

Let us take now, on Figure 27, the beginning *A* of two wall-arches, two pointed arches and one transverse arch. Let *A B* (Fig. 28*b*), be the surface of the wall, *C D* the directrix of the

transverse arch, $D E$ the directrix of the diagonal arch; we outline the projection of the wall-arch as above. The diagonal arches govern the transverse arch. From each side of the line $D E$ we measure off 0.20 centimetres, and draw the two parallels $F G$ and $H I$ which give us the width of the diagonal arch. From the point H, the meeting of the line $H I$ with the axis $C D$ upon that line $H I$, we take 0.45 centimetres, that is to say, a little more than the height of the voussoirs of the diagonal arch, and we draw the perpendicular $I G$, which gives us the face of the diagonal arch.

In the parallelogram $F G I H$ we outline the appropriate contour.

From the two sides of the axis $C D$, measuring off in the same way 0.20 centimetres, we draw the two parallels $K L$ and $M N$.

From the point H, measuring off 0.40 centimetres upon the axis $C D$ from H to C', we draw a perpendicular $L N$ to that axis, which gives us the face of the transverse arch, and then we outline its contour.

At P, we imagine that the column bearing the wall-arch passes above the beginning of the diagonal and transverse arches; at R, we suppose that the contour of the wall-arch has fallen vertically upon the abacus of the capital. In order to draw this wall-arch in this latter case, we take upon the line $A B$, from the point M to Q, 0.40 centimetres, and from this point Q, erecting a perpendicular upon the line $A B$, we have the parallelogram, including the contour of the wall-arch. The abaci of the capitals are drawn parallel to the faces of the arches, as our figure shows.

From the vertices G and L, drawing lines at an angle of 45°, we meet the axis $D E$ at O, which is the centre of the pillar carrying the diagonal arches, and the axis $C D$ at S, which is the centre of the column of the transverse arch. We outline these columns conformably to the rule previously established.

Behind these detached columns, we suppose the location of the pilasters that reinforce the piers; then the wall-arch R falls upon a face of these pilasters carrying capitals like the columns.

Often the wall-arches did not descend to the abacus of the capitals of the great arches, and also had no pillar supporting them from the floor. They started upon a pillar placed on the lateral projection of the abacus, as Figure 29 indicates, both in horizontal section and in perspective elevation. Then the abaci of the lateral pillars *A* were cut in such a way that their oblique face *C D*, perpendicular to the

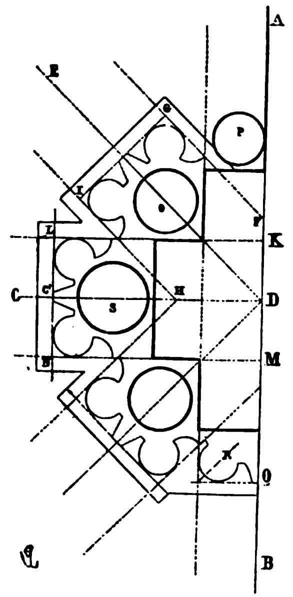


Fig. 28*b*.

Fig. 29.

directrix *B* of the pointed arches, was divided into two equal parts by that directrix.

Still, it must be recognized that the builders only little by little decided to indicate the form, direction and members of the vault upon the ground-plan. They kept for some time the monocylindrical piers on the ground-floor, while outlining the plan governed by the vaults only, upon the abaci of the capitals of these piers.

What occupied them after the end of the twelfth century was the rigid observance of a principle which had hitherto been universally admitted. This principle was that of the equilibrium of forces, substituted for the principle of inert stability, which was so well practised by the Romans, and which the Romanesque builders had vainly tried to preserve in their large, vaulted edifices, composed of several naves.

Recognizing the impossibility of giving to the detached piers an impost sufficient to resist the thrust of the vaults, the builders of the twelfth century took a new course: they sought their means of resistance elsewhere. They were no longer willing to admit the detached pillars, except as supports maintained upright, not by their own base, but by the laws of equilibrium. It was of importance, then, only that they should have a force sufficient to resist a vertical pressure.

There are always, even when a principle is admitted for a certain time during its application, blind attempts; one never frees himself from traditions in one day.

In inventing the diagonal-arch vaults on a square foundation and crossed by a transverse arch, the builders still sought points spaced off between each pair of compartments, more stable at the height of the principal pressures.

In fact, in Figure 27, the points *A* receive the weight and maintain the thrust of one transverse and two diagonal arches, while the points *B* receive the weight and maintain the pressures only of one transverse arch. This system of vault-building, adopted during the second half of the twelfth century, induced the builders to erect under the points *A* piers stronger than those under the points *B*, and then to give to the voussoirs of the principal transverse arches falling on *A* a width and thickness greater than those given to the voussoirs of the diagonal and secondary transverse arches; for in the early Gothic vaults, it is to be remarked, as we have already said, that the voussoirs of all the arches generally present the same section.

The arch in tierce-point was so well regulated by the necessity of diminishing the thrust, or resisting the weight, that we see in the early Gothic buildings, the broken arch uniformly adopted for the transverse arches and the lower archivolts, while the semicircular arch is kept for the bays of windows, for the arcades of galleries, and even for the wall-arches, which carry only a slight weight or present only a small opening.

In the Cathedral of Noyon, whose primitive vaults must have been raised about 1160,[1] the wall-arches which belong to that period are semicircular. In the Cathedral of Sens, built about this same time, the wall-arches were semicircular,[2] while the archivolts and transverse arches are in tierce-point.

It is the same with the choir of the abbey church of Vezelay, built at the end of the twelfth century; the wall-arches are semicircular.

In these edifices, particularly at Sens, the piers, under the combined pressure and weight of the diagonal and transverse arches present a very considerable horizontal section, formed of clusters of engaged pillars; while under the weight of the transverse arches alone the piers are composed of monocylindrical twin columns, placed perpendicular to the axis of the nave.

At Noyon the intermediate transverse arches, before the rebuilding of the vaults, rested upon a single column. But the nave of the cathedral of Sens is much larger than that of the cathedral at Noyon; and the building is at all points stronger. That arrangement of vaults having two divisions and distributing the principal pressures and weights upon pairs of piers, had originally allowed the builders to place flying-buttresses only at the height of the principal piers.

It is probable that in the Cathedral of Sens, this was formerly the plan adopted; perhaps it was the same in the Cathedral at Noyon

[1] These vaults were rebuilt in the thirteenth century, over the great nave, only the original wall-arches being left in place.

[2] These wall-arches were raised at the end of the thirteenth century, as one can still see by the divisions of the apse.

as in that of Paris; but these edifices having been more or less restored in the thirteenth century, it is impossible to affirm anything in that respect. What we may be certain of, is, that at the end of twelfth century, the builders had adopted the flying-buttress in despair, since they were seeking to avoid it as far as possible, and since they distrusted this means whose advantages and power they were not yet able to appreciate; and that they regarded it only as an auxiliary, a last resort, often an afterthought, and when they had learned that they could not do without it. The best proof that we can give is that some years later the architects, having finally submitted, in the edifices with three naves, their system of vaults to the law of equilibrium, opposed flying-buttresses to the thrust of vaults which had possessed them only partially or not at all, and did away with the flying-buttresses of the twelfth century, probably misplaced, or insufficient, in order to replace them by new and well arranged buttresses, as regards the resistance or the pressure.

We must, before going further, inform our readers concerning the processes of construction, and the nature and dimensions of the materials employed. We have seen, at the beginning of this article, how the early Romanesque constructors built their masonry, composed of concrete, enclosed between the facings of cutstone, or of dressed rubble.

The builders of the twelfth century added some modification to these first methods. Building edifices more vast in extent and taller than those of the Romanesque period, and seeking to diminish the thickness of the interior supports and of the walls, it was necessary for them, on the one hand, to find a mode of construction more homogeneous and capable of resistance; and, on the other hand, to avoid, in monuments already of great height, the expense of labor which the carrying up of materials of great size would have occasioned. Henceforth they gave up the use of large facing-stones (except in particular instances or in some exceptional edifices) and preferred to build with small facing-stones, resembling rubble rather than the

cut-stone. As far as possible, the greater part of the stones then used to form facings or voussoirs of archivolts, transverse and pointed arches, are in pieces small enough to be carried upon a man's back, and laid by a mason like our ordinary stones. The method once adopted, this little facing is very well made, very judiciously combined; it is a middle course between the Roman construction in large facing-stones, and that of rough stones included between brick or stone walls. In adopting the small facing-stones in large edifices, the builders of the twelfth century had too much sense to lay these low and shallow courses with free joints, like certain Romanesque constructions; on the contrary they separated these courses by beds and joints of thick mortar (from 0.01 to 0.02 c.), in order that these beds might form a link between the interior masonry and the facing. This method was the Roman method, and it is a good one.

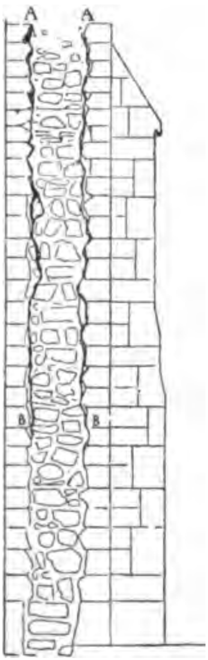


Fig. 30.

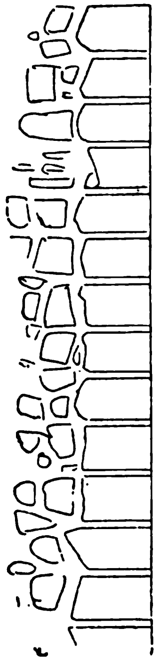


Fig. 30*b*.

The reader will understand, in fact, that if (Fig. 30) these courses are laid without mortar in front of a masonry of rubble and mortar, the rubblework having settled because of the drying of the mortar

under the pressure, and the courses of stones, set directly one upon another, being unable to diminish in volume, a vertical rupture *A B*, will take place behind the facing, which will not be long in falling. But if (Fig. 30 *b*) we have taken care to leave between the courses of stones a thick bed of mortar, not only will this bed, made fast to the masonry, hold the stone-facings, but it will also permit the facing to undergo a settlement equivalent to that of the interior mass.

The early Romanesque builders, especially in countries where one can procure large hard stones, as in Burgundy, Franche-Comté, and Alsace, upon the Saône, and the Rhône, did not fail to mimic the Roman facing, by setting broad, high squares of flagging, so to speak, without mortar, in front of the filling: but they paid dearly for this desire to make their constructions appear other than they were. There took place in the majority of these edifices, ruptures between the facing and the filling, longitudinal crevices which caused in nearly all of them serious disorders at least, and often utter ruin. These effects were the more frequent and dangerous, as the edifices were more elevated. Better advised, and taught by experience, the architects of the twelfth century, as much for reasons of economy and facility of execution, as to avoid this want of homogeneity between the facings and the filling, adopted the construction in courses very shallow and separated by thick beds of mortar. These beds had not only the advantage of settling down and binding the facings to the filling; but being made of mortar of a fat lime they became hard gradually, and, while waiting for perfect solidification, the structures had time to settle down, undergoing even certain changes of form, without occasioning any breaks in the masonry.

The buildings raised from 1140 to 1200, in Ile-de-France, Beauvais, Soissons, Picardy, Champagne and Normandy, are built with facings surprisingly small; for already these edifices are vast, of complicated and yet very light structure. To employ cut ashlar in such constructions as the principal material was highly audacious; to

succeed was the work of very skilful men. If one examines with care the facing of the portions belonging to the twelfth century in the Cathedrals of Noyon, Senlis and of a great number of churches in the departments of the Oise, the Seine, the Seine-et-Oise, of the Seine-et-Marne, of the Marne, of Seine inferieur, etc., he is astonished that builders have dared to raise monuments so light and of so great height, with means that seem so feeble; and yet the stability of these edifices has long since been assured, and if some among them have undergone sensible alterations, that is due almost always to particular accidents, such as fires, want of repairs, or subsequent overloading.

Of all these monuments, one of the most perfect, and the best preserved is the Cathedral of Noyon, built from 1150 to 1190. Except the smaller pillars, the large capitals, the abutments, and some exceptional portions, the whole building is composed only of rubble having little resistance.

One will obtain an idea of this construction from our Figure 31, which gives a part of the two interior divisions of the nave.

The isolated pillars of the gallery above the aisle, those of the little triforium above, and those separating the high windows are monoliths of hard stone set against the stratum.

As to the small triple columns *A*, which before the rebuilding of the vaults in the thirteenth century, received the transverse arch at the intersection of the diagonal and wall arches, they are composed of large pieces, held contrary to the cleavage, at intervals, by cramps in the form of a T.

But these pillars were set up after the structure had entirely settled down, and they are really only a decoration, and support nothing; the course of the capital and the abutment, whose extremities are held fast in the masonry, being sufficient to sustain the voussoirs of the transverse arch.

We have indicated in *B*, the starting-point of the old diagonal arches of the great vaults, and in *C*, the wall-arch behind the diagonal arches.

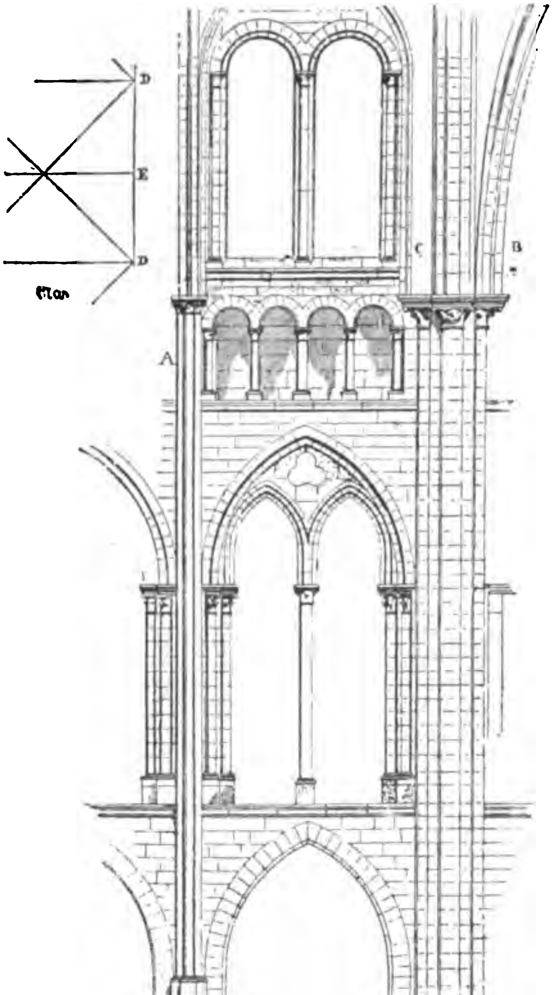


Fig. 31.

It will be remarked that, here, as in the majority of the churches built at that period, in the provinces bordering on Ile-de-France, and notably, in the Beauvoisis, the piers which support the extremities of the diagonal and transverse arches are much heavier than those which support only the transverse arch.

In other words (see the plan), the piers *D*, are composed of a cluster of pillars, while the intermediate piers *E*, are only monocylindrical on the ground-floor, surmounted by the cluster of pillars *A*.

The extreme lightness of such a construction, the facility with which all the materials which compose it, can be cut, lifted, and set in place, explain how, even with feeble resources, one could think of building edifices of great extent, and raised high above the ground. To-day when we have formed the habit of using enormous masses of stones of huge size in our least important edifices, and of employing forces of ten times greater resistance than is necessary, we should not dare to undertake to build a cathedral as large as that of Noyon, with means apparently so feeble, and we should expend fabulous sums in executing what in the twelfth century they could do with comparatively the smallest resources.

We find these constructions expensive, because we will not employ the processes then in use.

Yet the Cathedral of Noyon has stood for seven centuries and, provided it can be repaired suitably, it can last five hundred years longer; now twelve hundred years appears to us a reasonable duration for a building, since the great social revolutions to which humanity is subject, will destroy them anyhow, even if they are able to continue for a longer period.

Besides offering advantages of economy, of facility in getting materials, and of execution, the structures built with small materials were also perfectly suited to the system adopted by the architects of the twelfth century.

These light buildings, showing on their ground-plan considerable voids as compared with the solids, and submitted to oblique

pressures, and to the laws of equilibrium which took the place of the Roman laws of inert stability, demanded in all the members which composed them a certain elasticity.

There, where the builders, less imbued with the new principles then admitted, sought to reproduce forms that the lay artists of the twelfth century had adopted, without exactly knowing the reason for their existence, while using material of large dimensions, were produced in the buildings fractures such that the equilibrium was soon broken.

If the arches were not perfectly independent of one another, if upon one point they had placed materials of great height and size, and if beside them the structure was made only of stones in small pieces, the parts, being rigid, or too firmly attached to the whole, or too heavy, presented a resistance, which had no other result than to cause breaks and crevices; while the too solid parts of the structure crushed or dragged down the weak parts.

Let us, observe again, that, in these monuments, the piers, of a slight horizontal section, receive all the weight and that by reason of the small surface of their beds they ought to settle much more than the walls, for example, which support nothing, since they are relieved of the weight of the roof, and the upper masonry by the wall-arches.

If, in this system, there is complete solidarity between these weighted points of support and the unweighted filling, enclosures, and walls, there will necessarily be a rupture.

But if, on the contrary, the builders have taken care to have every weighted point preserve an independent function, and be able to move and settle freely; if the accessory parts are only enclosures independent of the effects of pressure or thrust, then ruptures cannot take place, and the looseness of the masonry is favorable to the endurance of the structure instead of being injurious.

The Romans, who opposed only passive resistance to the thrusts, had perfectly admitted this principle of looseness, of liberty between

the weighted parts of vaulted constructions and those which are not loaded. The great halls of the ancient baths are in this matter triumphs of combination. The whole system consists of piers supporting the vaults; the walls are only enclosures built afterwards, which one can take away without in any way injuring the solidity of the general framework of the building. Here are principles very natural and very simple; then why not always put them into practice? These principles the Gothic builders have carried much farther than the Romans, because they had, as we have said many times, adopted a system of construction where every force is active, and where there are no inert resistances, as in the Roman constructions, to act by their compact mass.

The builders of the twelfth century, raising their large edifices on plans whose solid parts cover little surface, and with light materials, in opposing to oblique thrusts active resistance in place of passive obstacles, were not slow to perceive that it was always necessary to find somewhere that inert stability. If they raised flying-buttresses against the walls of the vaults at the points of their thrusts, these flying-buttresses ought, in order to fill their rôle effectively, to find an immovable impost; that impost was found in an exterior support, a sort of pier raised on the outside of the buildings, and on which all the thrusts are concentrated. To give to these buttresses a horizontal section broad enough to preserve the immovability of their mass at a great height, was to encumber the outside of these edifices with heavy masonry which kept out the light and air, and which became very expensive. The builders had no longer the recipe for that mortar which was the principal agent in the great Roman constructions, and the piers which they might have raised would not have had the necessary cohesion. It was essential then, to find the means of substituting for the inert resistance of the Roman supports a force quite as powerful, but derived from a different principle. This was to load the supports destined to maintain the thrusts until they attained a weight sufficient to resist the action of these thrusts. It

is not necessary to be a builder to know that a prismatic or cylindrical pier built with courses of stone placed one upon another, and having more than twelve times its diameter, cannot stand upright unless it is weighted at its upper end. In this well-known law of statics the Gothic architects believed that they had found the means of erecting edifices whose supports might be slender, provided they were loaded with a weight capable of rendering them rigid enough to resist oblique and contrary thrusts.

In fact, let us suppose a pier *A B* (Fig. 32), acted upon by two oblique and contrary thrusts *C D* and *E F* acting at different heights; the stronger thrust, that of *C D*, being 10, and that of *E F* being 4. If we load the top of the pier *B* with a weight equivalent to 12, not only the thrust *C D* is annulled, but still more so that of *E F*, and the pier will remain upright. Not being able to load the piers of the naves with a weight great enough to annul the thrusts of the great vaults, the builders resolved to oppose to the pressure *C D* a flying-buttress *G*. Hence the weight *B O*, increased by the pressure *C D*, becoming 15 for example, the pressure *E F* is annulled.

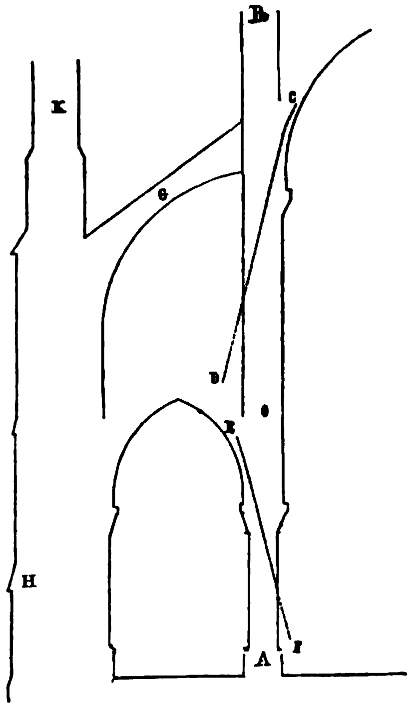


Fig. 32.

If the flying-buttress G opposes to the thrust $C\ D$ a resistance equal to this oblique pressure and neutralizes it completely, the thrust $C\ D$ becomes a vertical pressure upon the pier $A\ B$, and the only thing necessary is to sustain the oblique action of the flying-buttress upon the exterior buttress. Now, if this oblique action is in itself 8, it is not increased by the whole of the thrust $C\ D$, but only by a slight part of that thrust. It is something like 10, or 12 perhaps, in certain cases. The exterior support H, opposing already, by its own mass, a resistance of 8, it will be sufficient to load it with a weight, K, of 5, in order to maintain the general equilibrium of the building.

We shall take care not to solve by algebraic formulas these problems of equilibrium that practice is incessantly modifying, in proportion to the nature of the materials used, the size of their pieces, the quality of the mortar, the resistance of the ground, the action of external agents, and the greater or less care applied to the construction. Formulas are good to exhibit the knowledge of him who gives them, but they are almost always useless to the practical worker; the latter allows himself to be directed by his instinct, his experience, his observations, and that feeling, innate in every builder, which shows him what he ought to do in each particular case. We do not hope to make builders out of those to whom nature has refused that quality, but to develop the instincts of those who possess it.

One cannot teach good sense or reason, but one can learn to make use of the one, and to listen to the other.

The study of the Gothic construction is useful because it does not adopt those absolute formulas which are always neglected in execution by the practitioner, and whose least danger is to cause men to receive error with that confidence that truth alone should inspire.

If the Gothic construction is not submitted to absolute formulas, it is the slave of certain principles. All its efforts and improvements tended to convert these principles into laws, and laws they obtained as the result.

It was equilibrium; forces of compression opposed to forces of divergence; stability obtained by weights reducing the different oblique forces to vertical loads, and as a consequence, the reduction of the horizontal sections of the supports; such are these principles, and they are still those of true modern construction; we speak not of that which blindly seeks to reproduce edifices built under conditions foreign to our civilization and our needs, but of the construction that considers our modern needs, our social conditions.

If the Gothic builders had had at their disposal cast-iron in large pieces, they would have availed themselves eagerly of this sure means of obtaining supports as slender as possible and yet rigid, and perhaps they would have used it with more skill than ourselves. All their efforts tend, in reality to the balancing of forces, and to considering the supports, henceforth, only as slender supports kept vertical, not by their own breadth of base, but by the complete balance of all the oblique thrusts which act upon them. Do we ourselves do otherwise in our domestic constructions and in our great institutions for the public use, where the needs are so imperious that they silence the teachings of routine? And if any fact ought to surprise us, is it not to see to-day, in the same city, the erection of houses, markets, depots and warehouses, which rest upon slender supports, and cover considerable surfaces, while leaving to the solid walls, a scarcely appreciable foothold; and to see, at the same time, structures where the stone, collected in profusion, is heaped up, block on block in order merely to cover surfaces comparatively small, and to support only floors exercising no oblique pressure? Do not these facts indicate that architecture has strayed from the path marked out for it by our needs and our modern spirit? That it is seeking vainly to protest against those needs and that spirit? That the time is not distant when the people, wearied by an art which tries to disregard their needs under pretext of maintaining classic traditions for which they care little, will set aside the architect among the archæologists, good for enriching our museums

and our libraries with their learned compilations, and for amusing certain societies with their barren discussions. Now, we repeat, Gothic construction, despite its defects, its errors, its attempts and perhaps because of all these, is a pre-eminently useful study; it is the surest initiation into that modern art which does not yet exist but is struggling, because it establishes the true principles to which we ought still to submit to-day; because it has broken with antique traditions, and because it is fertile in applications. It matters little whether a bell-tower be covered with ornaments which are not to the taste of such and such a school, if this bell-tower have a reason for its existence, if its function be necessary, if it permit us to take up less room on the public way.

It matters little that the pointed arch shocks the eyes of the exclusive partisans of antiquity, if that arch be more solid and have more resistance than the semicircular, and we save a considerable amount of stone. It matters little whether a column has twenty or thirty diameters, if that column suffice to carry our vault or our flooring. Beauty is not, in an art wholly conventional and logical, linked forever to one single form; it can always reside there when the form is but an expression of satisfied need, of judicious use of the material given. Because the multitude sees in Gothic architecture only its ornamentation, and because this ornamentation no longer belongs to our time is this a proof that the construction of these edifices can no longer find an application? One might just as well maintain that a treatise on geometry is worth nothing because it is printed in Gothic characters, and that students reading in this book that "the angles opposite the vertex are equal to each other," are learning mere folly and are being misled. Now, if we can teach geometry with books printed yesterday, we cannot do the same in construction, and we must necessarily seek these principles where they are traced — in the monuments; and this book of stone, strange as are its type and its style, is as good as any other, in reality, as to the ideas that it has suggested.

In no other order of architecture do we find these ingenious and practical means of solving the numerous difficulties which surround the constructor living in the midst of a society whose needs are complicated to excess. Gothic construction is not, like antique construction, immutable, absolute in its means; it is supple, free, and as inquiring as the modern spirit: its principles permit the use of all the materials given by nature or industry in virtue of their own qualities; it is never stopped by a difficulty; it is ingenious: this word tells all. The Gothic builders are subtile, ardent and indefatigable workers, reasoners, full of resources, never stopping, liberal in their methods, eager to avail themselves of novelties, all qualities or defects that place them in the front rank of modern civilization. These builders are no longer monks submissive to rule or tradition; they are laymen who analyze everything, and recognize no other law than that of reason. Their faculty of reasoning scarcely halts at natural laws, and if they are forced to admit these, it is in order to conquer them by opposing them one to another. If that is a fault, does it become us to reproach them?

We must be pardoned for this digression, since it is necessary in order to explain the meaning of the constructions of which we are about to give numerous examples. Knowing the tendencies, the independent spirit of the Gothic builders, their patient labor amid a society which had scarcely begun to be organized, our readers will better appreciate their efforts and the feeling that stimulated them. Perhaps, like ourselves, they will find in these daring innovators the bold modern spirit, perplexed but not baffled by routine and the prejudices of system, or by exclusive dogmas.

We have seen at the beginning of this article that, if the Roman construction is in all points excellent, wise, harmonious, like the social organization of that people, when once discovered, it proceeded steadfastly in the same path, following invariably the same laws, and employing the same means of execution to the end of the later empire.

It was good, it was admirable, but it could not undergo a change. The principal strength of the Roman people lay in preserving their social organization despite the most evident symptoms of dissolution. Their architecture proceeded in the same way; we see, under the last pagan emperors, the execution debased, the taste degenerating, but the construction remaining the same; the Roman edifice is always Roman.

Except for the spherical vault upon pendentives, which appeared at Byzantium when the Roman Empire was nearing its end, there is no progress, no change, no effort. The Romans built as bees make their cells: it is marvellous, but the hives of to-day are lined as the hives of the times of Noah. If we gave to the builders of the Baths of Titus cast-iron, forged or plate iron, wood and glass, and asked them to make a hall, they would tell us that no one could build with these materials. The modern spirit is different: tell it to build a hall, with a section of twenty metres, out of pasteboard, and it will not reply that the thing is impossible; it will try, it will invent means for giving stiffness to the pasteboard, and we can rest assured that the hall will be built.

The Roman marks out the plan of his edifice with great intelligence. He takes the necessary bases, and proceeds with assurance: there is no anxiety during the execution. He is certain of the result beforehand; he has taken all the necessary precautions, he erects his building with security, nothing can oppose his projects; he has known how to guard against all accidents, and he sleeps peacefully while his edifice is raised upon immovable bases. What could he lack? Room? He takes it. The materials? He finds them everywhere; if nature refuses them to him he manufactures them. The labor, the transportations, the money? He is the master of the world. The Roman is a superhuman being: he has something of the measured grandeur that one attributes to the Deity; nothing can fetter his power. He builds as he wills, and where he wills, on the site that he chooses, with the aid of workmen

who are blindly obedient to him. Why should he set about creating difficulties for himself? Why invent machines able to carry the water of rivers to a great height, when he can seek their source in the mountains, and bring them into the city by a natural slope, over vast plains? Why struggle against the regular order of things in this world, when the world, both men and things, belongs to him?

The mistake of the early periods of the Middle Ages was in believing that, in the state of anarchy into which society had fallen, one could repeat what the Romans had done. Moreover, although this period of transition follows the traces of Roman traditions, what powerlessness! what wretchedness! But soon there arises the spirit of modern society; to this vain desire to revive an extinct civilization succeeds the antagonism between men, the strife with matter. Society is broken up, the individual is responsible, all authority is contested, because all the powers neutralize one another, and are victorious turn by turn. They discuss, they investigate, they hope. Among the débris of antiquity, it is not the arts that they are going to exhume, but philosophy, the knowledge of things. Already, in the twelfth century, it is among the Greek philosophers that the chosen intellects seek their weapons. Then that society, still so imperfect and so wretched, is on the right road; its instincts serve it well; it takes from the remains of the past what may throw light on the future and help men to go forward.

Vainly the clergy struggle against these tendencies; despite all the power at the disposal of clerical feudalism, it is itself dragged into the controversy. It sees rising about it each day the spirit of examination, discussion, criticism. Furthermore, at that period, everything which tends to abase one power is supported by a rival power. The national genius profits skilfully by these rivalries; it gathers form and courage; always materially subjugated, it makes itself morally independent, and follows its own course through the struggles of all these powers, too little enlightened to exact from the intelligent throng rising about them anything else than a material

submission. Many others before us have said, with more authority, that political history, the history of great powers, as it was formerly written, presents only one narrow side of the history of nations, and, in fact, illustrious authors of our own time have shown that we can know the life of the people, their development, the causes of their change and their progress, only by searching into their own hearts. But what no one has yet written is the history of those energetic, active, intelligent men, strangers to politics, war and trade, who, in the midst of the Middle Ages, took so great a place in the country; of those artists or artisans, if one prefers, organized into corporations; obtaining extensive privileges through the need that people had of them and of their services; working in silence, no longer under the vaults of cloisters, but in the *atelier;* selling their material labor, but keeping their genius independent and ready for novelty; keeping themselves closely united, and marching together toward progress, in the midst of that society which made use of their minds and their hands without comprehending the liberal spirit which animated them.

Let others undertake a task merely outlined here by us; it is a noble one, and sure to awaken sympathy. It embraces questions of the highest order; perhaps it might throw light upon certain problems of our day which occupy, not without cause, all clear-sighted minds. A thorough knowledge of the past is, in our opinion, the best means of preparing for the future; and of all the classes of society, that one whose ideas, tendencies and tastes vary the least is certainly the laboring class — that which produces. In France, that class demands more and other things than its daily bread: it demands the satisfaction of its self-respect; it demands the right to keep its individuality; it wishes difficulties to solve, for its mind is still more active than its hands. If it needs material occupation, it also needs moral occupation; it wishes to know what it does, and that people approve what it does. Every one admits that this spirit reigns among our soldiers, and assures their preponderance. Why

not, then, recognize its existence among our artisans? To speak only of buildings, workmanship has declined among us at the periods when men have tried to submit individual labor to diverse Classic rules established by an absolute power. Now, when workmanship declines, social crises are never far off in France. Of all the industries, that of building certainly occupies the greatest number of hands, and demands from each man a rather high degree of intelligence. Masons, stone-cutters, lime-makers, carpenters, joiners, locksmiths, roofers, painters, carvers, cabinet-makers, upholsterers, with the subdivisions of these different classes, form an innumerable army of workmen and artisans acting under one directing force, being disposed to obey it and even to second it when it is enlightened, but soon out of control when that directing force is opposing its own nature. Our workmen and our artisans hear and follow only those who can tell where they are going and what they want. The word WHY is perpetually in their mouths or in their glances, and there is no need of remaining long among workmen engaged in building in order to know with what mocking indifference they labor at things for which they see no reason, and with what zeal they execute works whose practical utility they perceive. A stone-cutter does not work as carefully over a block which he knows is to be hidden in masonry as he does over a stone to be in sight, whose useful function he knows. All the injunctions of the overseer can do nothing against this feeling. It is, perhaps, an evil, but it is a fact easily verified in the building-yard. *Regard for appearances* is the common weakness of France, and, not being able to overcome it, one must make use of it. People declare that we are Latins, in our language, perhaps; but in our manners and tastes, in character and spirit, we are not so any more to-day than in the twelfth century. Coöperation in the common work is active, devoted and intelligent in France when men know that this coöperation, feeble as it may be, will be seen, and hence appreciated; it is languid, lazy and careless when men suppose it overlooked in the general mass. We beg our readers

to examine well this national spirit, too long disregarded, in order to understand the meaning of the examples that we are about to place successively before their eyes.

To familiarize ourselves with an art whose resources and practical means have been forgotten, we must first enter into the spirit and the innermost feelings of those to whom that art belongs. Then everything is deduced naturally, everything harmonizes, and the aim appears clearly. We do not pretend, moreover, to disguise any of the defects of the systems presented; this is not a plea in favor of the Gothic construction, but a simple exposition of its principles and their consequences. If we are well understood, there is no sensible architect who, after having listened to us with some attention, will not recognize the uselessness, to say no more, of *imitations* of Gothic art, and who will not understand at the same time the advantage that one can derive from the serious study of that art, and the innumerable resources presented by that study so closely allied to our genius.

We are about to pursue the examination of great religious constructions, first, because they are the most important, and, next, because they are developing rapidly at the end of the twelfth century, and because the principles in accordance with which these edifices are erected are applicable to every other construction. We know now the successive phases through which the construction of these vaulted edifices had to pass, in order to change from the Roman to the Gothic system; in other terms, from the system of passive resistances to the system of active resistances. From 1150 to 1200 they were building in the Royal domain, in the Beauvoisis and Champagne, the great churches of Nôtre Dame at Paris, at Mantes, at Senlis, at Noyon, the choir of Saint Remy at Rheims, at Sens, and of Nôtre Dame at Chalons-sur-Marne, all after the new principles adopted by the lay school of that period, all having preserved a perfect stability in their principal works.

CHAPTER VI.

VAULTS.

IN every thing experience or practice precedes theory, fact precedes law; but when the law is known it serves to explain the fact. We observe that all bodies are heavy, and that some force draws them toward the centre of the globe. As yet we know nothing of the pressure of the atmosphere, of the force of attraction, of the shape of the earth; we know only, that every heavy body, if left to itself, is drawn vertically toward the ground. From the observation of the fact, we deduce laws, and whether these laws be true or false, it does not at all alter the nature of the fact or its recognized effects. The builders of the twelfth century had not defined the laws to which the voussoirs of an arch are subjected, namely their weight and the reaction of the two adjoining voussoirs. We know to-day, from theory, that if we seek on each bed of these voussoirs the point through which the resultant of the pressures acting upon them passes and if we draw a line through these points, we thus determine a curve called the *curve of pressures.*

We discover, again, by the aid of algebraic calculation, that if one wishes the equilibrium of the voussoirs of an arch to be perfect, this curve of pressures, whose first direction at the key-stone is horizontal in a semicircular arch, must not touch upon any point in the lines of the intrados and extrados of the arch. This curve of pressures, prolonged down through the arch, when it rests upon piers,

determines what is called the *thrust:* then, the nearer the arch comes, in its development, to a horizontal line, the farther that thrust is from the vertical; and the farther the arch from being a horizontal line, the nearer is the thrust to the vertical. The Gothic builders had only the instinct of this theory. Perhaps they possessed some of those mechanical formulas that we still find mentioned by the authors of the Renaissance, who have treated of these matters, and give them not as discoveries of their time, but, on the contrary, as traditions good to follow. With regard to the thrusts of arches, for example, they made use still, in the sixteenth century, of a very simple geometrical formula for estimating the strength to be given to abutments.

In Figure 32*b* we have this formula. Given an arch having *A B* as its diameter, to find in relation to the nature of that arch, what should be the thickness of the piers capable of resisting its thrust. We divide the semicircle or the pointed arch into three equal parts, *A D*, *D C*, *C B*, from the point *B*, as a centre, we describe an arc having *B C* for a radius. Then we pass a prolonged line through the points *C* and *B*. Its point of meeting *E* with the arc of which *B* is the centre, will give the outer facing of the pier whose thickness will be equal to *G H*. If we proceed in the same manner upon the pointed arches, dividing them always into three equal parts, we shall obtain abutments as much less thick as these arches are the more acute, as our figure shows. Of course this process is only applicable to arches mounted on piers of equal height for these different arches, and if not more than one and one-half times the diameter of the base of these arches. It is probable that the early Gothic architects made very simple rules for themselves in ordinary cases; but it is certain that they referred only to their own judgment whenever they had some new difficulty to solve. As if they had determined the laws for the pressure of arches, they arranged to concentrate the resisting materials upon the path of these lines, and thus conducting the pressures from the top of the

vaults to the ground they arrived, by successive steps, at considering everything outside as useless, and suppressing it.

We wish to be understood by everybody and will not deal in definitions. Let us take an example.

Let Figure 33 be a Roman semicircular cradle-vault; let *A B* be the curve of pressure of the voussoirs, and *B C* the thrust. If the wall that supports this vault has the height *F D*, its thickness must be *C D*. Since all the oblique pressure of the vault bears upon the point *C*, of what service is the triangle of construction *E D F*? Suppose now that we have a Gothic vault (Fig. 34) in pointed arches; the resultant of the three oblique pressures *B A*, *C A*, *D A*, in the plan will be a line *A E*, and in the cross-section a line *G H*.

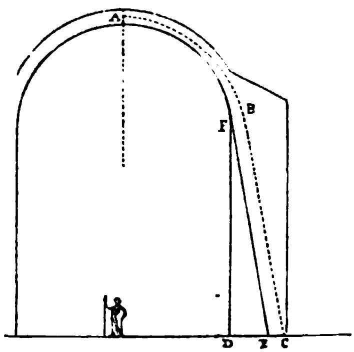


Fig. 33.

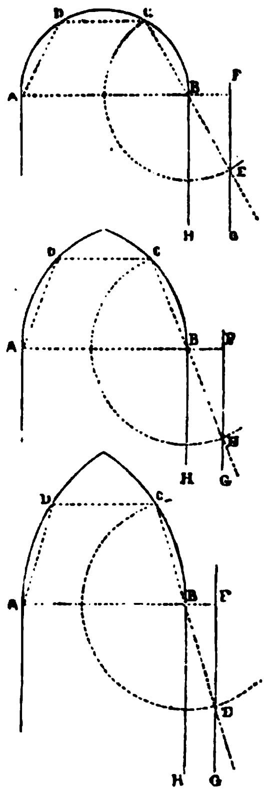


Fig. 32*b*.

The instinct of the builder indicating to him this principle, he will arrange his whole construction to relieve this point; in other words, he will move back the vertical support *I O*, and place a capital *M*

whose projection shall unite with the direction of the thrust *G H*. In *O* he will have a corbel and in *I* a relieving-capital so as to bring *P*, the axis of the lower column, as near as possible to *H*, the point of arrival of the thrust *G H*. But being forced in the edifices with three naves, to leave this point *H* outside of the axis *P* of the column, he no longer considers the latter except as a support that must be kept vertical by equilibrium. He then neutralizes all the lateral action by building the flying-buttress *K*. But, some one will object, why keep the relieving-wall (or facing) after the thrust of the great vault is neutralized by the pressure of the flying-buttress? It is here that the subtlety of the builder appears. That thrust *G H* is neutralized, but it exists; it is a force overpowered but not suppressed. ✓ The flying-buttress checks the effects of that thrust; that is its only function, for it cannot take away this oblique action. Let us not forget that there is a lower vault, *L*, whose thrust can act only upon the column *P*, and that this thrust can be suppressed only by the vertical weight exercised by building from *R* to *S*; that this vertical weight will have as much more power as it is increased by the thrust of the great vault, and that since the meeting of these two forces, vertical and oblique, takes place in a single point *S*, upon the capital, it will exactly buttress the pressure exerted by *L S*. To determine this action by calculations would be a sheer waste of labor, for these calculations must vary infinitely by reason of the height or breadth of the spaces, the thickness of the walls, the quality of the material, their resistance, the height of the courses, etc. But the human instinct, when it is acute, is always more subtle than calculation; just as there is no machine, however perfect it may be, which attains the delicacy of the hand and the sureness of the eye. In this case, the instinct of the first Gothic builders served them well, for all the naves built with monocylindrical columns arranged as indicated in our cross-section (Fig. 34), are rarely put out of shape to a perceptible extent; while the majority of those where the piers, composed of clusters of pillars, rise from the ground, are

bent more or less at the height of the thrust of the lower vaults. But we shall have occasion to return later to this subject.

This first point having been cleared up, let us come now to the details of the execution; for this is necessary. Gothic construction proceeds (if we are permitted to avail ourselves of this comparison)

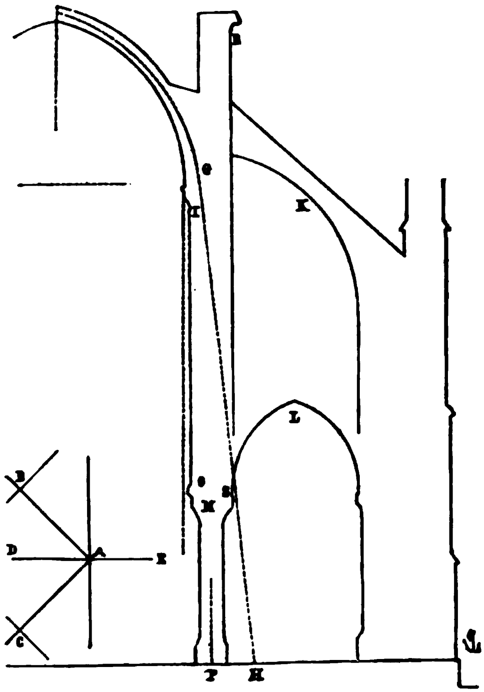


Fig. 34.

from an organic system much more complicated than that of the Roman construction. "So much the worse," say some, "it is a mark of inferiority." "So much the better," say others, "it is a proof of progress." Progress or decadence, it is a fact that we must recognize and study. Already, Figure 34 has shown that the

combination by means of which the thrusts of vaults are maintained in Gothic buildings is by no means simple. Now, every construction starting from a complicated principle brings a series of consequences that cannot be simple.

Nothing is so imperiously logical as a building erected by men reasoning out what they do; we shall see this at once. The choir of St. Remy of Rheims was rebuilt about 1160, at the time when they were constructing that of the Cathedral of Paris. This construction, very skilfully conceived in its whole, showed in its details only a series of attempts; which indicates a school already far advanced in theory, but of very little experience in execution. The principle of weight and equilibrium which we have previously outlined, are there rigidly applied. But evidently workmen and overseers in the building-yard were lacking to these first Gothic builders; and they neither had the time nor the means of training skilful laborers, for no one understood them. Furthermore, the choir of St. Remy of Rheims must with reason have excited the admiration of the builders at the end of the twelfth century, for the methods there adopted are followed in Champagne at that period, and notably in the rebuilding of the choir of the church of Notre Dame at Chalons-sur-Marne.

But first let us describe in a few words the history of this charming edifice. The church of Chalons-sur-Marne was built during the early years of the twelfth century. It then consisted of a nave with aisles; the nave was roofed over, probably by timbers resting on transverse arches, like many of the churches of that period in Champagne; and the aisles were vaulted by means of transverse arches separating Roman groined vaults. The choir was composed of an apse without aisles, but with two square chapels opening into the transepts, under two steeples, like the cathedral of the same city. Toward the end of the twelfth century (although this structure had been raised under excellent conditions, and nothing leads us to the supposition that it had deteriorated), these arrangements were no longer in harmony with the ideas of the time: they were now wishing

for vaulted naves, with aisles and chapels radiating out around the chancel. So the church had to undergo a complete rebuilding: the circular wall of the apse was replaced by detached columns; they built an aisle opening into three circular apsidal chapels; they kept the two steeples which flanked the apse but pierced the wall at the floor of the square chapels arranged under these towers, and these served to communicate with the aisle of the apse.

The nave was made higher and completely vaulted; and in place of the Roman vaults over the aisles they built pointed vaults. Some capitals taken down from the original structure were replaced, notably in the side aisle of the apse.

This historic summary shows how much they were disposed to profit by all the resources presented by the new system of architecture then hardly sketched out. The construction of the apse of the Church of Notre Dame at Chalons-sur-Marne is a very little later than that of the choir of Saint Remy of Rheims, but already it is more scientific; one still perceives many blind attempts, and yet the progress is perceptible.

We ought here to resume the matters previously under discussion. We have described the simple groined vault raised between parallel walls, and we have indicated the first efforts of the architects to build and maintain this on its piers. We must return to this subject and examine the varieties of these vaults.

From the eleventh century, already, they had surrounded the chancels of churches by aisles with or without radiating chapels. (See "*Architecture Religieuse.*") That method, foreign to the plan of the early basilica, had caused builders more than one perplexity. Roman antiquity left nothing similar to it. Certainly the Romans had built porticos upon a circular plan, but these porticos, if vaulted, were composed of thick piers supporting a cradle-vault in which two semi-cylinders met, forming groined vaults, or a succession of radiating cradle-vaults fixed on arches, or even on horizontal imposts faced in stone, as still seen in the amphitheatre of Nismes.

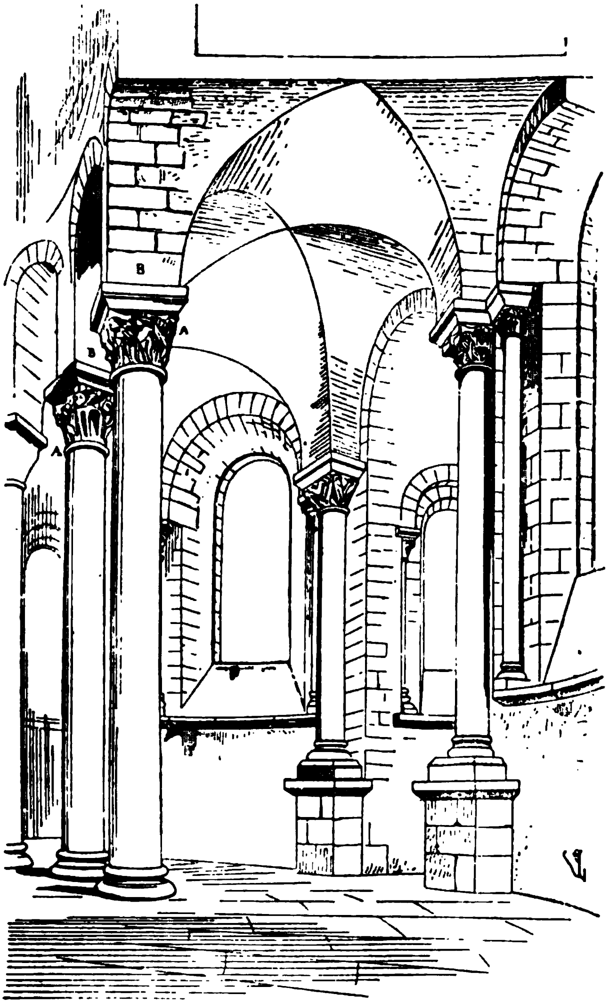


Fig. 35.

But the Romans had by no means the idea of placing groined vaults over porticos formed of detached monocylindrical columns, for that could not agree with their principle of inert stability. What the Romans had not done, in that as in many other things, the builders of the Romanesque period attempted. They wished to surround the chancels of their churches with porticos or concentric aisles following the curve of the apse, and to give as much light as possible to these porticos by supporting the vaults on detached columns, which were to cover them. In the first instance, as in the churches of Auvergne and Poitou, they were satisfied with a cradle-vault on a circular plan, cut by the intersection of arches from one column to another. To buttress the thrust of these cradle-vaults on the inside, they relied at first on the weight which bore down on the columns, and then on the circular form of the apse which offered to these thrusts a great resistance. The aisles of the apses are thus vaulted in the churches of Notre Dame du Port, at Clermont, at Issoire, at Saint Nectaire, at Saint Savin near Poitiers, etc.

Figure 35 explains this method, without the need of further development.[1]

But when during the twelfth century, the builders had introduced the system of vaults with pointed arches, they naturally wished to apply it everywhere, and thought, with reason, that it was impossible to keep in the same edifice the system of Roman groined vaults beside the new style. Easy as it was to place upon the oblong abacus of the capitals *A*, the skew-backs *B*, shaped so as to receive a simple groined vault, so much more difficult did that become when the groined vault yielded to transverse and diagonal arches. This difficulty was not the only one.

If we represent a section of the plan of the apse of the Church of Notre Dame du Port with its aisles (Fig. 36) we shall see that the intersections of the semi-cylinders *A* and *B* in the circular cradle-vault *C C′* give, in horizontal section, the two lines *E F* and *G H*

[1] The aisle of the choir of Notre Dame du Port, at Clermont.

crossed. We observe that the portico being on a circular plan, the opening *H F* is greater than the opening *E G;* that, if we should build one semicircular arch over *H F* and another over *E G,* this latter would have its key much lower than the former; that the intersection of the semi-cylinder whose diameter is *E G,* with the circular cradle-vault *C C′*, would be outlined in horizontal section by the line *E′ L G′*, and that consequently there would be no groined vault, but simply the intersection of a small cylinder with a great one. To obtain a groined vault, *E F G H,* the builders raised the semicircular arch drawn above *E G,* as the revolved section *I K M* indicates by taking a height *N M* equal to the radius *O P.*

Thus the abaci of the four engaged and free columns *R, S, V, T,* being on the same level, the two keys *M* and *P* were found in the

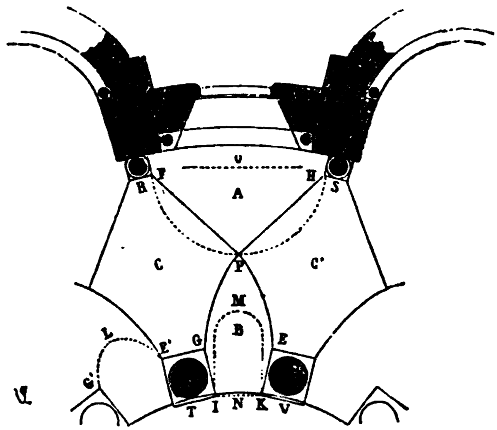


Fig. 36.

same horizontal line which governed the length of the radius of the cradle-vault *C C′*.

The idea of raising semicircles upon the isolated columns *T* and *V,* was then no caprice, or barbaric whim, still less an Oriental

imitation, as men have sometimes claimed, but the result of a very simple calculation on the part of the builder.

This first step taken, let us now see how the architects of the twelfth century, inaugurating the use of the diagonal-arch vault on a circular plan, tried to go farther. Let us not forget that one of the motives that had led them to adopt the diagonal-arch vault, was the desire to get rid of certain troublesome necessities imposed by the antique groined vault: the need of independence felt by the builders. But independence in building, as in everything else, is acquired only after abortive attempts. The architects of the twelfth century felt sure that their principles were fertile in application, that they would lead them to surmount without effort the difficulties in the building of great edifices; yet, as it always happens, these principles at once so simple and so adaptable, embarrassed them cruelly in the immediate application; and in order to remain loyal to them they complicated their buildings, and being unable to rid themselves altogether of old traditions, but wishing to reconcile them with their new ideas, they fell into infinite difficulty. Yet far from being discouraged, they clung after each attempt to these new ideas with the zeal and persistence of a people wholly convinced. We shall see them at work in the Cathedral of Langres, one of the most instructive monuments in France, and certainly one of the best built. There, ancient traditions have considerable sway; Langres is a Roman city in a district covered but a few centuries ago with numerous Roman edifices almost intact. But let us come to the fact that concerns us particularly, to the vaults with diagonal arches over the aisle of the chancel.

The monocylindrical column, which even in purely Gothic structures lasted so long, is employed in the choir of the Cathedral of Langres. These columns have the proportions of the Roman Corinthian column, and their capital is quasi-Roman; but (Fig. 37) their abacus is already arranged with a view to what it must support; two of its sides are not parallel, and they form an angle in order

to avoid irregular surfaces at the intrados of the archivolts *A*, that they carry; and on the side of the aisle this abacus gives a broken line in order to offer a projecting support to the transverse arch *B*.

In *X* we give the horizontal projection of these abaci. Feeling the necessity of separating the transverse arches and of leaving a

Fig. 37.

place for the diagonal arches to start, and fearing the action of the thrust of the vaults upon the columns, in spite of the circular form of the apse, the architect has surmounted this abacus with a projecting corbel *C*.

As our figure shows, the diagonal arches D scarcely find room to start, yet the instinct of the artist has led him to ornament that starting-point in order to disguise its inadequacy. There are three skew-backs one upon another. The first two, E and F, have their beds horizontal, while the third, G, has its sections normal to the curve of the arch. So these arches succeed, not without difficulty, in disengaging themselves from the square plan, and even the diagonal arch must make its way between the voussoirs of the archivolts and of the transverse arches.

But now the builder wishes to double his archivolt A with a second arch I which shall intersect the diagonal arch, for the wall surmounting these archivolts is thick, and carries a semidome or oven-shaped vault. It is, then, only above the diagonal arch and when this leaves the abutments that one can fix the second arch I. This is not all, for since these vaults radiate, the architect has drawn his diagonal arches in plan, as indicated in (Fig. 38); the surface K

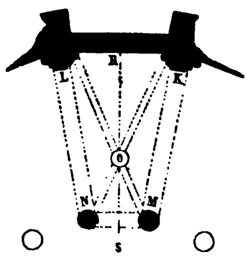


Fig. 38.

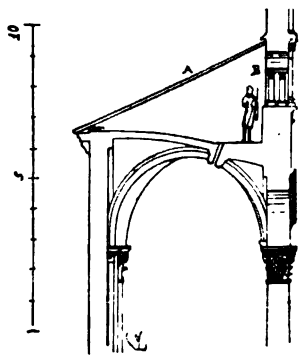


Fig. 39.

$L\ M\ N$ being a trapezium, the builder yet supposing it impossible to draw diagonal arches forming in their horizontal projection broken lines, the key O is nearer to the line $M\ N$ than to the line $K\ L$.

The arch $K\ L$ having its summit on a higher plane than that of

the arch *M N* (for they have not dared to make that higher), the line *R S* slopes from *R* to *S*.

(Fig. 37) shows this arrangement, and the section (Fig. 39) explains it still better. Moreover a construction of this kind, whether preconceived or produced by chance, presents advantages: it allows the light entering under the wall-arches of the vaults to pass from the aisles into the midst of the chancel; it does not waste the height of the sloping roof at *A;* the slope of this roof and that of the vault give room for the gallery *B;* moreover it offers a great resistance, in that it throws a large part of the weights and thrusts upon the interior semi-cylinder which, forming the vault, runs no risk of separating off in slices and leaving its centre.

At Notre Dame du Port the abaci of the capitals (Fig. 36) give parallelograms in their plan, so as to offer a thick enough impost for the wall of the chancel; and the result is that the arches raised over these abaci present irregular surfaces and cones rather than semi-cylinders.

At the Cathedral of Langres, the abaci of the capitals are outlined, as we have noticed, in angular form, in order to keep at the intrados of the archivolts curved surfaces which are exactly parts of a cylinder. Thus they avoided a difficulty of facing and of warped surfaces displeasing to the eye, but the angular abaci made the capitals ungraceful. When looked at parallel to the diagonals they presented on the side of the aisle an angle of greater projection than on the side of the chancel. The architects of the Gothic school soon freed themselves from these perplexities, and learned how to avoid these difficulties.

Our readers will at once see why we have lingered over the drawing, and the mode of constructing the vaults radiating from the aisles of the apses. One word more before proceeding to the improvements introduced by the Gothic architects. These had originally adopted two methods of neutralizing the thrust of vaults: the first method was that of restraining the effects of these thrusts

by a force acting in opposition; the second, which one might call the *preventive method*, consisted in destroying these effects at the outset, or, in other words, in hindering them from acting. They employed one or the other of these two methods according to the need: sometimes they profited by the effects of the thrusts, though without permitting them to destroy the general equilibrium, as we have seen in Figure 34 and sometimes they annulled them and reduced them at once to a vertical pressure.

A very simple drawing will explain the application of these two methods.

Let (Fig. 40) there be a vault, the resultant of whose pressures is the line *A B*, we can establish a construction like that given in our drawing.

In supposing the stones *C* and *D* to be of a single piece each, having resistance, and fastened at the end under the buttress, this construction will be more solid than if we had built a pier *E A* from the ground, under the skewbacks of the vault.

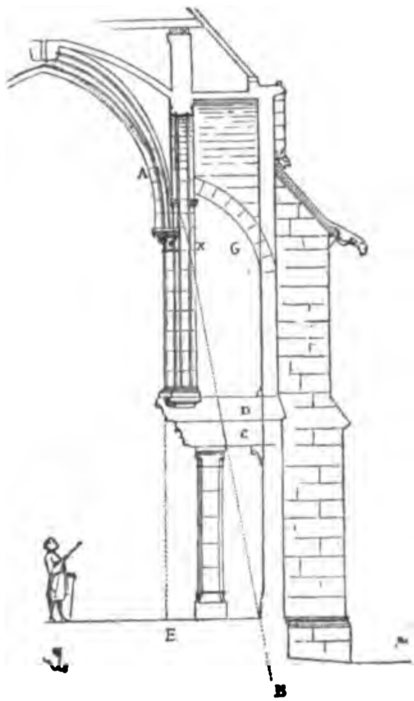


Fig. 40.

In this drawing we profit by the effects of the thrust *A B*, and we draw it off according to its direction.

The flying-buttress G and its masonry are there only to hinder the vault from spreading in a horizontal direction.

Let us notice, in passing, that the flying-buttress does not weigh upon the pier X, and that it does nothing but counteract the thrust

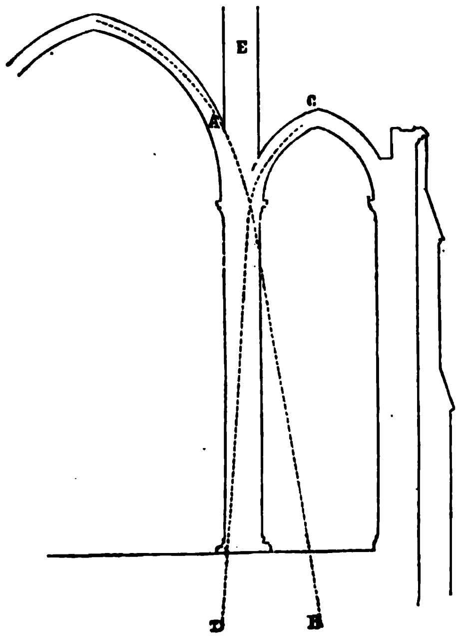


Fig. 40*b*.

of the vault at the point where the curve of pressures tends to come out at the extrados of the voussoirs.

This is the method which restrains the effects of the thrusts, but by using them as an element of equilibrium.

Now, let (Fig. 40*b*) there be a vault, the resultant of whose

thrust is the line A B. If, in place of a flying-buttress we oppose to the thrust A B a less powerful thrust C D, and if we place a weight E to bear upon the extremities of the two vaults, we reduce the oblique thrusts to a vertical pressure; we prevent their effects, they do not act. This is what we call the *preventive method.*

There is, then, this very subtile distinction between these constructions: First, the flying-buttress is simply an obstacle opposed, not to the oblique pressures, but to their effects, if the equilibrium should be disturbed; Second, it permits the builder to profit by these oblique pressures in his general system, without fear of seeing the economy of this system deranged by some action beginning outside of the equilibrium.

But the entire attention of the builders, for that very reason, is brought to bear upon the perfect stability of the supports receiving the thrusts of the flying-buttresses; for the equilibrium of the forces of the different parts of an edifice depends upon the stability of the exterior abutments. Still the architects often will not or cannot give these abutments a sufficient thickness in proportion to their height; so they must make them firm by factitious means.

We have an example of the use of such means in the church of Saint Remy of Rheims, though seen still more clearly in the choir of the church of Notre Dame at Chalons, to which we now return.

We first present (Fig. 41) the plan of a part of that apse, in A at the ground floor, in B at the height of the vaulted gallery, in C at the height of the triforium and in D at the height of the springing of the vaults. We see, on the ground plan, how the architect has avoided the perplexity of building a vault with diagonal arches, over a trapezium. He has placed at the entrance of the chapels the columns E, which have allowed him to draw a vault E F G upon the parallelogram. Therefore the transverse arch E H is similar in width and height to the transverse arch F I, and the line I H through the key of the triangular fillings is not inclined, as at Langres, from the outside inward. From E to K a second trans-

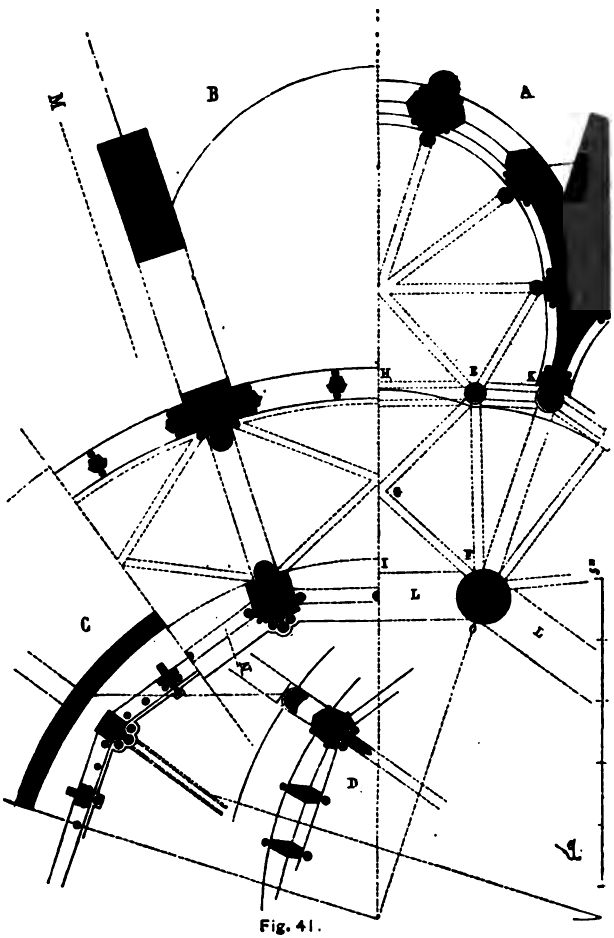


Fig. 41.

verse arch unites the column E to the pier K, and there remains a triangle $K\ E\ F$, easy to vault since it is only a portion of ordinary filling.

The method is the same at Saint Remy of Rheims, but not so well exemplified.

It will be seen that these higher plans fit exactly over the ground plan unless there is some deviation, whose necessity we shall at once recognize.

There is one important fact, in the construction of the choir of Notre Dame of Chalons, in that it shows the efforts of the master-builder to clear away certain difficulties which had perplexed his confrères at the end of the twelfth century.

It will be observed that the plan of the chancel gives angular faces on the interior and a semicircular curve on the exterior. In the same way the lower archivolts *L* connecting the great columns on the ground-floor, are ranged along the sides of a dodecagon, while the archivolts of the gallery on the first story are on a rectilinear plan over the chancel, and on a curved plan over the gallery. The outer wall of this gallery is also built on a semicircular plan, and the triforium (Plan C) is on a rectilinear plan within, and curved without. It is the same with the upper windows (Plan D).

The architect had wished to avoid the perplexity given by the construction of archivolts or of transverse arches over a semicircular plan of a rather small radius. He feared the thrusts into vacant space, and keeping the circular form only on the outside, and changing it to a dodecagon in the inside, he united very skilfully the advantages of the two systems; in other words, great lines of walls and concentric bands, a simple arrangement without, but combining great solidity with a graceful effect in the chancel; for arches opened in a circular wall of small diameter always have the effect on the eye of very disagreeable lines.

A perspective view (Fig. 42) of the aisle with the entrance to a chapel will render the arrangement of the ground-floor easy for all to understand, and will indicate its construction.

The detached columns of the chapels are monoliths, 30 centimeters in diameter at the most; the rest of the construction, except

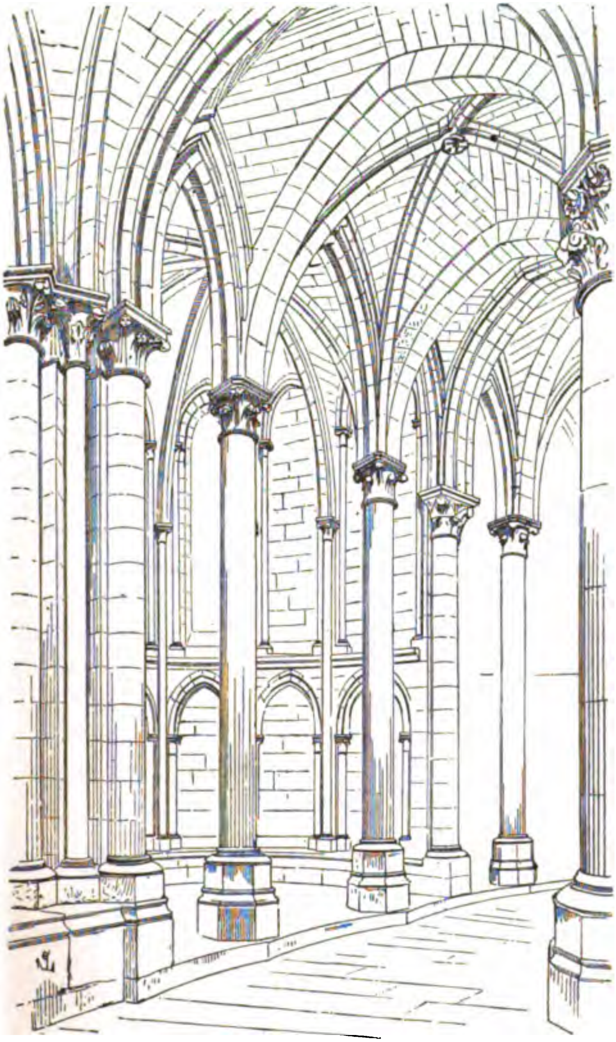


Fig 42.

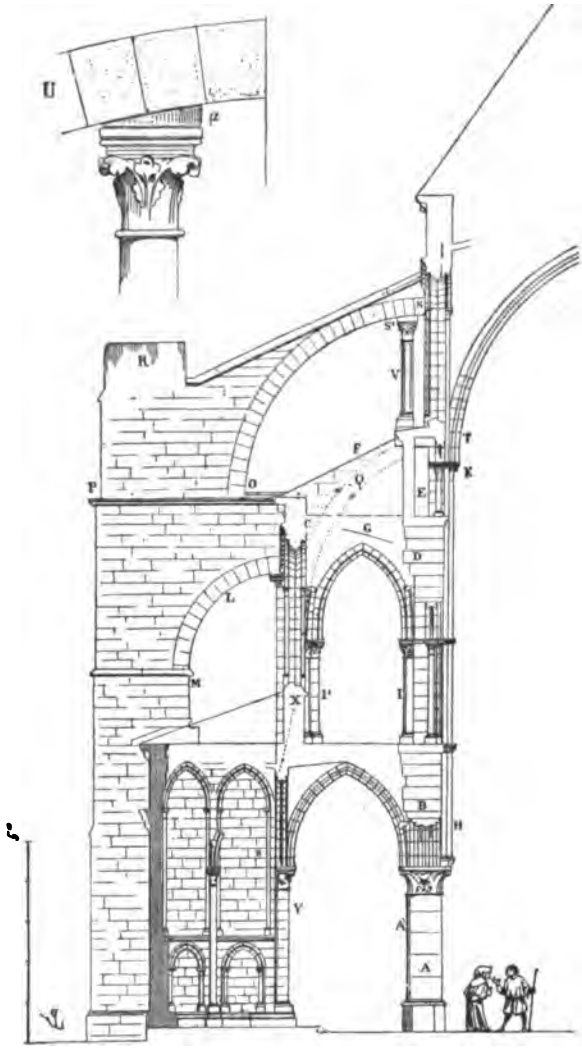


Fig. 43.

the pillars at the angles of the chapels and those of the windows, are built in courses.

We now give (Fig. 43) the cross-section of this building as far as the vaults, following the line *M N* of the horizontal plan.

This section shows us at *A*, in conformity with the method then used in Ile-de-France and the adjacent provinces, the monocylindrical columns marked *O* upon the plan; at *B* the archivolt and the separation of the vaults of the aisle. The principal churches of that period and that province all have a vaulted gallery on the first story. (See "*Architecture Religieuse, Cathédrale, Eglise.*")

Here the vault slopes, like that of the aisle in the Cathedral of Langres, and this is not without motive (see plan B, Fig. 41).

In fact, the wall-arch *C*, being wider at the base than the archivolt *D*, has its key higher up, which allows the cutting of large windows suitable for lighting the choir.

The triforium *E*, occupying quite a large space between the key of the archivolts of the gallery above the aisle and the sills of the upper windows, allows a roof *F* to be built over that gallery, with a sufficient slope in spite of the inclination of the vault *G*.

Let us examine this section with attention.

We see that the abacus of the capital of the pier *A*, receives as a corbel the base of the column *H*, which supports the skeleton of the vault; this pillar and the two others flanking it and supporting the wall-arches do not unite with the building, but are composed of great blocks of stone set contrary to their cleavage.

It is the same with the pillars resting against the gallery and the engaged column *I*. Thus the pier at the height of the gallery is a parallelopipedon composed of courses and surrounded by columns set contrary to their cleavage like *posts* of timber in order to keep their *rigidity* under the weight and pressure from above.

It is the same with these piers at the height of the triforium *E* (see plan C); the core is built of stone courses, and the pillars around it on three sides are set contrary to their cleavage.

The large pillars at the top are fastened by bands, forming rings, to the main part of the construction, by their base and the capital K under the skewbacks. To maintain this equilibrium it was necessary to have recourse to flying-buttresses. It will be seen in the ground-plan (Fig. 41) that the architect wishing to make his chapels as open as possible, placed behind the pier K, only a very light partition of stone.

He could not build upon that partition a solid abutment; moreover he had propped the vaults of the gallery above the aisle by a first flying-buttress L (see cross-section) transferring that thrust to the more distant abutment of the gallery wall. But he lacked space on the exterior, and he did not wish the projection of the buttresses to pass beyond the circular line surrounding the chapels. This abutment was then not deep enough, and unable to resist the thrust of the large flying-buttress. So instead of starting the large buttress from the perpendicular of the facing M, the builder has changed the starting point to O.

He thus obtained from O to P a powerful abutment, and if he weighted the haunches of the lower buttress L, the latter gained great resistance, first, from the extraordinary size given to it, and next from R, the load above, which pressed on its abutment. Moreover, to avoid the effect of the thrust of the great vault between the head of the large flying-buttress S and the starting-point of the vaults T, he placed upon the outer wall of the triforium E, a column V, contrary to its cleavage, which stiffened that space perfectly, just as a strong post of timber might have done.

Also, under the impost T which forms a lintel in the triforium and juts out a little beyond it, the architect placed an arch Q, which was a powerful prop to all the upper part of the construction,[1] and offered even greater resistance to the arch L.

[1] These arches have since been destroyed and replaced by masonry and timbers, when the roof was rebuilt in the fifteenth century. It would be timely to think about rebuilding them.

Knowing the effects of the thrusts of the gallery vaults and of the flying-buttress *L*, which was destined to annul them, and fearing the action of the thrust caused by too broad a vault upon the interior piers at the height of the gallery above the aisle, the architect moved the pier *X* out of the perpendicular line of the lower column *Y*, since he had no reason to fear a vertical pressure on this point, but much rather an oblique thrust from *X* toward *Z*. As to the large flying-buttress, its voussoirs pass toward the centre of the arch over the column *V*, as if this column did not exist; and under the upper voussoirs the abacus of the capital forms an angle with these voussoirs, as indicated in the detail *U*; a simple stone wedge *a* fills the angle between the abacus and the voussoirs.

It is here that we perceive the fineness of observation and even subtlety of these early Gothic builders.

It was possible, in all the height of the pier from *A* to *E*, that some settlement might occur, and by reason of this settlement the top *S* of the great flying-buttress might suffer, and exercise such a pressure on the column *V*, that this latter would give way, or in resisting, would cause at *S'* a rupture fatal to the safety of the arch.

Placing the column as outlined in *U*, the lowering of the summit of the flying-buttress can only make the abacus slip a little under the arch, and hence bend the column *V* somewhat. In this situation, resulting from a settlement of the great buttress, that column *V* would press upon the arch *Q*, and push against the pier *X* obliquely; which would not be dangerous since that pier *X* is put there to act obliquely; furthermore, the column *V*, would bear heavily upon the wall of the triforium, which supports it, and therefore upon the adjoining column *I*, an important point, for that column *I*, a monolith and independent of the pier behind it, being heavily weighted and unable to settle, transfers the principal pressure of the pier to the outer facing *A'* of the circumference of the lower column, or, in other words, upon the point where it is necessary to obtain a much greater

rigidity, to prevent the effects of the thrusts from the vaults of the aisle.

In this there is calculation and foresight; for it will be remarked that the engaged column *I'* facing that at *I*, is built in courses like the pier *X*; it was, in fact, important that this intermediate pier *X* should not have the rigidity of the inner pier, and that it should be

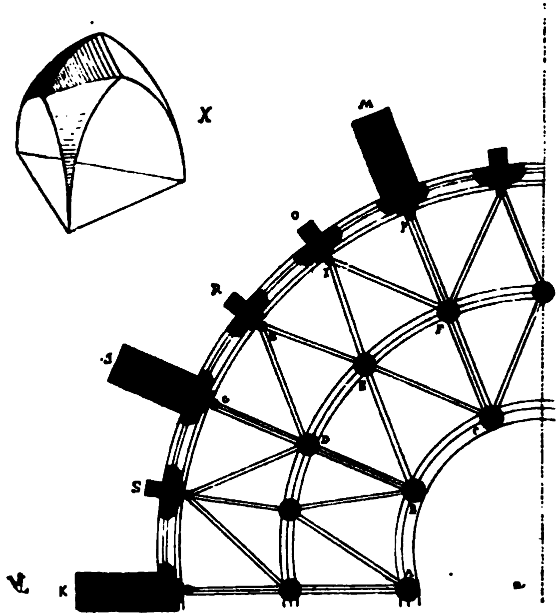


Fig. 44.

able to yield to the settlement in order not to cause a rupture from *O* to *L*, if the large buttress should settle down, a thing which could not fail to take place.

Accordingly then, in this construction the two systems of *preventive* and *opposed* resistances, explained in our two figures (40 and 40*b*) are simultaneously employed.

All this may be subtle, too subtle, we grant; but as to being coarse or barbaric, it certainly is not.

The builders of that time experimented incessantly, and routine gained no hold upon them. In experimenting, they discovered, they went forward and never said "We are at the goal, let us stop here." This, it seems to us, is a sufficiently good doctrine to follow. We to-day wish an architecture for our own time, a new architecture; it is very well to wish it. But we must know how to find a new architecture. It is not to be done, apparently, by forbidding the study of that art which is most fertile in resources of all kinds, most supple and most free in the use of material means.

Nevertheless a difficulty arose, serious enough and wholly new, when they came to the vaults of double aisles surrounding chancels of great extent. The examples that we have just given belong wholly to edifices of moderate dimensions, and we see that at Saint Remy of Rheims, and in the Church of Notre Dame at Châlons, for instance, the outer boundary contains a greater number of supports, than the one within, in order to avoid too great openings between the arches.

In a choir like that of the cathedral of Paris, surrounded by double aisles, it was necessary to arrange the piers in such a manner as to make the openings of the transverse arches nearly equal, in order to obtain vaults whose keys should all reach the same level. The two outer boundaries ought, then, to contain a greater number of piers than the boundary of the chancel. In the cathedral of Paris, in fact, we see (Fig. 44), that the circular part of the chancel, built about 1165, rests upon six piers, while the second boundary contains eleven, and the third fourteen. Thanks to that arrangement the archivolts *A B*, *B C*, etc., the transverse arches *D E*, *E F*, etc., *G H*, *H I*, *I P*, etc., are fixed on almost equal diameters, and the vaults connecting these arches are composed, in order to carry the stone-filling, of only the simple diagonal arches *B E*, *E C*, *F I*, *I E*, *E H*, *H D*, and no longer of intersecting arches.

In the gallery above the aisle the same system of vaults is used, and repeats the plan of the first boundary.

Figure X gives the form of these vaults raised upon the horizontal triangular plan.

The large buttresses $K J M$, alone maintain the stability of the edifice; they receive the flying-buttresses of the great upper vaults, and the small flying-buttresses of the gallery above the aisle, sprung from G to D, and from P to F, etc. As to the thrusts of the two diagonals, $B E$ and $C E$, of the vault of that gallery, they are resisted by two little flying-buttresses stretched from I to E, and from H to E. So that the principal thrusts and weights are thrown upon the large outer piers $K J M$, and the secondary thrusts and weights upon the intermediate exterior piers $O R S$.[1]

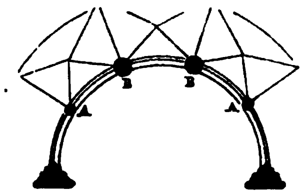


Fig. 45.

In the interior, monocylindrical columns alone support, on the ground-floor, this vast, tall edifice and rather complicated in the combination of its vaults. There is no need of being very expert in architecture to recognize, by merely glancing at Figure 44, that the evident intention of the master-builder was to occupy with his supports as little space as possible in the interior, and that he tried at the same time to cover the two aisles, by vaults whose summits should all be on the same level, in order to be able to place upon these vaults the floor of a gallery and flagging having a regular slope toward the outer perimeter.

A little after the building of that apse, the constructors, however, brought the piers A, B, C, nearer together, in such a way as to obtain around the chancel narrower divisions than those parallel to the axis, and they made the archivolts $A B$ and $B C$ still higher;

[1] It is understood that we are speaking here only of the early construction of the choir of Notre Dame at Paris, before the construction of the radiating chapels.

but we must recognize that there is in the arrangement of the circular space in Notre Dame at Paris an amplitude and freedom of conception very attractive to us.

The vaults are skilfully fixed on these piers, whose number increases at every boundary-line. This is easily done without effort and without experiment. Let us notice also that the Gothic vaults alone permitted the use of this method, and that the first architects who applied it in their building were at once able to reap its full benefit.

In the course of twenty-five years the architects of the end of the twelfth century had arrived at the results which had occupied their predecessors during the Romanesque period, namely: the vaulting of large and high buildings, while retaining within only slender supports. The triumph of the construction balanced by the opposition of thrusts and the addition of weights above, reducing these thrusts to a vertical action was then complete; and it remained only to simplify and perfect the means of execution. This was done by the builders of the thirteenth century, often with too great boldness and reliance on their principle of equilibrium, but always with intelligence. It was evident that sagacity was the dominant quality of the apostles of the new school. Their efforts tended unceasingly towards excelling the preceding work, toward carrying the consequences of the conceded principle even to abuse; so much so, indeed, that there was a reaction during the fourteenth century, and the buildings where the problems of equilibrium are solved with the greatest boldness are those which were erected during the latter half of the thirteenth century. We shall have occasion to return to this fact.

If one wishes to determine the utmost limit to which the architects at the end of the twelfth century arrived, in the matter of lightness of interior supports, and stability obtained by means of the equilibrium of opposing forces, he must visit the chancel in the church of Saint Leu d'Esserent (Oise).

Certain parts of this building, raised about 1190, are calculated to arouse our astonishment. This chancel is composed, in circular form, of four monolithic columns, two thick and two slender, arranged as in Figure 45.

The two columns *A* are only 50 centimetres in diameter, those at *B* being about 85 centimetres.

A perspective view of the two bays upon a circular plan, and resting on the columns *A* (Fig. 45*b*), clearly shows us after what we have just said, that the builders then relied only upon the equilibrium of acting and resisting forces, in order to sustain such a mass upon so slender a support.

We notice the column *A*, 50 centimetres in diameter, crowned by an extremely broad capital (see *Chapiteau*, Fig. 21), on which rest a powerful skew-back and the three monolithic pillars carrying the extremities of the upper vaults.

The skew-back is broad enough to receive the pier of the triforium and the wall which encloses it.

The exterior flying-buttress pushes the whole construction from without inwards, and the more the flying-buttress bears upon the top of the pier, the firmer footing does the construction obtain.

The enormous weight that the column *A* receives vertically, ensures its stability. The equilibrium cannot be broken, and, in fact, this apse has undergone no movement.

In Ile-de-France, however, the architects were able to keep within a certain limit, and never fell into the exaggerations so frequent among the architects of Champagne and Burgundy. Among the latter these exaggerations were justified up to a certain point by the excellent quality of the materials of that province, and the Burgundian architects, trusting to the extraordinary resistance of their stones, produced works of great importance from the builder's point of view, in that they show us how far the application of the Gothic principle can go when matter comes to its aid.

The vault being henceforth the generator of all the parts of

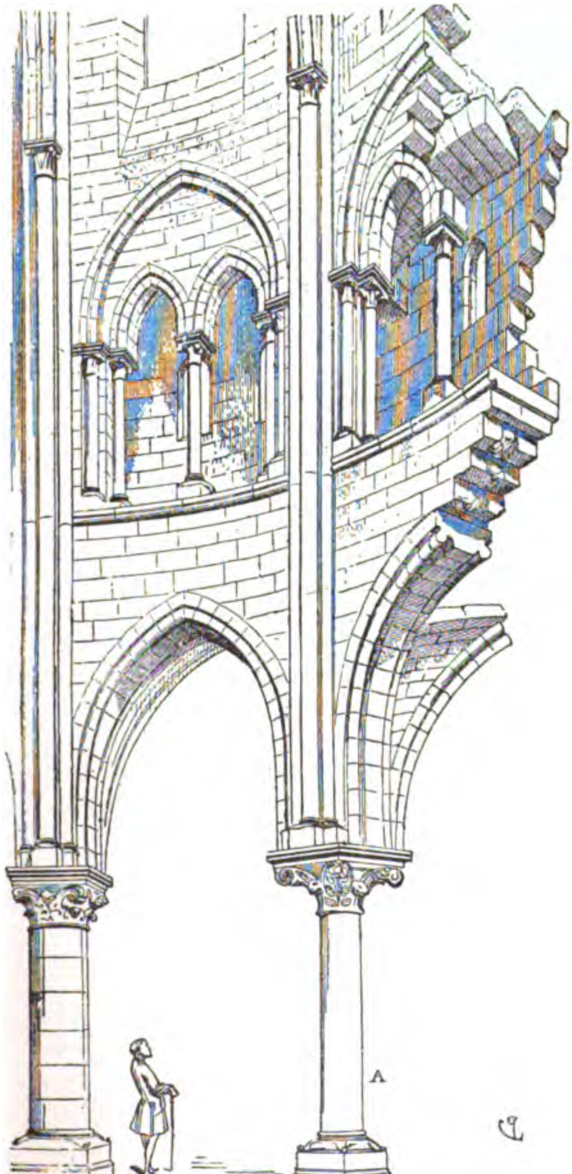
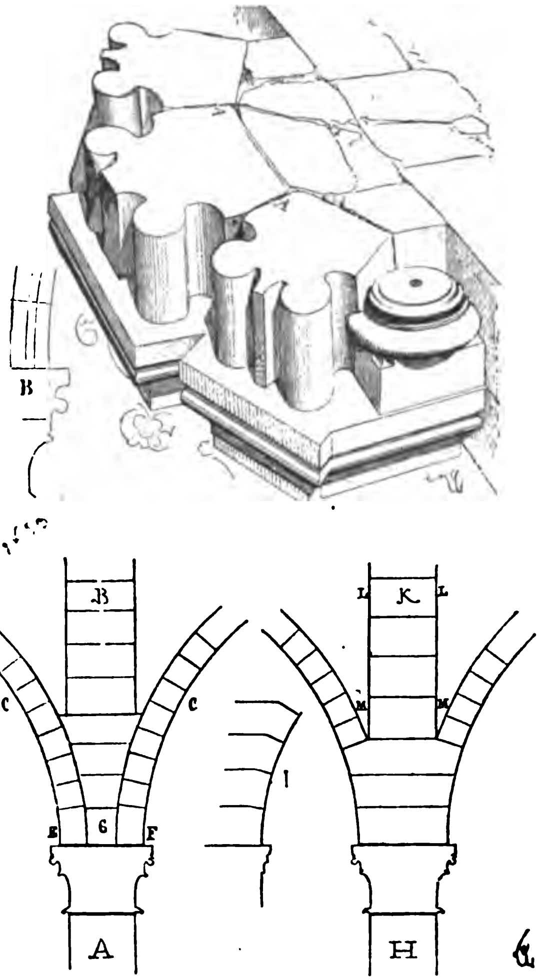


Fig. 45*b*.



Figs. 46 and 46*b*.

vaulted edifices, and governing the size, form, and arrangement of the supports, it is this that we ought scrupulously to study first.

For one who understands clearly the structure of the Gothic

vault, and the infinite resources that its construction presents, all the other parts of the masonry are naturally deduced. Our readers have already been able to gain acquaintance with the elements of vault-building; it remains to examine the details, the varieties and the improvements, for we cannot make ourselves clear unless, before going farther, the different means used to close the Gothic vaults are completely shown.

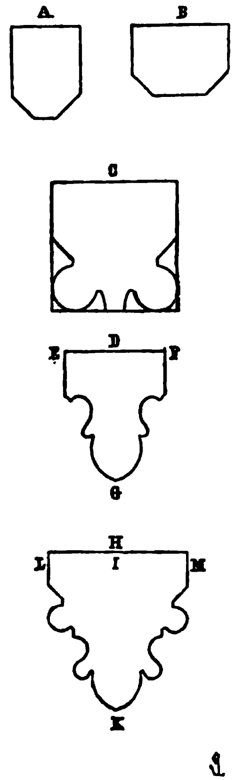


Fig. 47.

Figures 27, 28, 28*b* and 29 show how the lower beds of the abutments of arches on the abacus of the capital are drawn, and how these lower beds govern the form of the abacus and the position of the pillars and supports.

We easily recognize that in the first designs of Gothic vaults the builders have avoided, as far as possible, letting the arches intersect one another at their origin; they had each voussoir cut out according to the section given to each of the arches, and they tried to arrange them as best they could upon the abacus, trimming them off at the end to adapt their form to the intersections. Thus, for instance, having outlined upon the abacus of the capitals designed to receive a transverse arch, two diagonal arches, and the two pillars carrying the wall-arches, the bed of these different members, they fixed the voussoirs of each of these arches and the bases of the pillars as seen in Figure 46, cutting off the corners if necessary of the extremities of these arches, as seen at *A*, in order to place them side by side and fit them into their proper bed. This

naïve method required on the part of the designer no special plan for the abutment, but it demanded a large enough space on the abacus not to reduce too much the ends of the voussoirs, and hence very broad capitals; furthermore it had the disadvantage of giving only skew-backs without resistance, which might give way under their load, and extend the effects of the thrusts still farther, or bring their resultant near the outer facings. Given three arches to establish, the most natural idea was to allow them each a skew-back. But in certain cases the early Gothic builders had been forced, however, to permit the intersection of the different arches sustaining a vault upon a single isolated column, as seen in Figure 42, and to give only one skew-back for all of them; for upon these narrow imposts it was no longer possible of arranging the first voussoirs of these arches as one puts together the pieces in a game of patience; that would be making these first voussoirs into a conglomeration of angles without force of resistance. Moreover, it was necessary that the first voussoirs of these arches (if they had an upper pier to support), should form a flat bed, or, in other words, present actual horizontal courses, in order to resist the pressure.

Let, for instance (Fig. 46*b*) be a pier, *A*, having an upper pier, *B*, to support above a vault, *C*.

If the arches of this vault are all independent at their origin and have a complete extrados, and if the joints of the first voussoirs are normal to the curves, it is clear that the pier *B* will not rest upon the impost *E F*, as it ought, but upon the slight filling *G*, and, accordingly, its stability cannot be assured, while the pressure upon the back of the first voussoirs will inevitably cause disorder, rupture and downfall. Nevertheless, this was the method employed by the last Romanesque architects, and it often had disastrous results. In similar cases the early Gothic architects proceeded differently.

If *H* be the pier bearing an upper load, *K*, they placed as many horizontal courses, one upon another, as were necessary to give the verticals *L M* an impost, and began the arching of the

voussoirs normal to the curves only when these curves left the vertical surfaces *L M*.

Up to a certain height, then, the arches consisted of a series of courses with horizontal beds, and serving as corbels.

These builders had too much good sense to think of the ancones *I*, which can never be well arranged, and whose beds cannot be perfectly filled with mortar, and they preferred to adopt the corbels out and out. These had a further advantage, in that they partly destroyed the effects of the thrusts. We should not fail to say here that the face of the voussoirs, or skew-backs, is always set perpendicular to the upper surface of the corbel on the capital, as the drawing *B*, Figure 46, indicates; while as to the base of the pillar carrying the wall-arch, it is set close to the edge of the abacus, in order that the surface of the column may keep perpendicular to the surface of the corbel of the capital. (See the same, Fig. 46.)

From the time when it was admitted that one could place at the starting-point of vaults a series of courses with horizontal beds for superimposed arches, architects no longer needed to spend their time in finding a broad enough surface on the abacus of capitals to receive the voussoirs of several adjoining arches, but only to arrange that these arches should intersect upon the smallest possible surface.

Always rigidly following out their courses of reasoning, they recognized alike that the resistance of arches in the vault system newly adopted is dependent on the height of the voussoirs, and not on their breadth, and that, with sections equal as to area, a voussoir made, for example, as indicated in *A* (Fig. 47) would resist pressure much more than a voussoir made according to the outline *B*. Now, toward the beginning of the second-half of the twelfth century, the voussoirs of arches were generally included in a square section *C*, from eight inches (22 centimetres) to a foot or eighteen inches (33 centimetres to 50 centimetres) in the depth, according to the breadth of the vault, while, toward the end of that century, if the voussoirs of transverse arches still kept that section, those of diagonal arches

(arches whose diameter is much greater still, but which do not have to resist the pressure of the flying-buttress) lost a part of their breadth while preserving their depth, as seen in *D*. Having less breadth from *E* to *F*, their outline upon the abacus of the capitals took less space and required less width, while adapting itself better to the intersections, and having no more than one edge at *G*, or a simple roll, its sloping projection upon the abacus did not present the awkward and troublesome surfaces given by the arches whose section was *C*.

Little by little, the architects renounced that section *C*, even for transverse arches, and adopted sections analogous to that at *H*, offering in the same way from *I* to *K* a great vertical resistance, and from *L* to *M* a sufficient resistance of base to avoid the torsion already maintained by the filling of the vault.

Thus each day, or rather after each attempt, the architects arrived at the suppression of everything not absolutely indispensable to the solidity of the vaults, and abandoned the last Romanesque traditions in order to obtain :

1. Increased lightness of structure.
2. Facilities for laying the skew-backs, since these skew-backs were henceforth to govern the construction of the piers, and hence of all the lower members of the edifices.

But we are obliged, at the risk of seeming tedious in our explanation of the Gothic system of vaults, to proceed like the builders of that time and to follow, without leaving it for an instant, the march of their progress.

When these builders had admitted the flying-buttress, that is to say, a resistance opposed at certain points to the thrusts of the vaults, it was necessary to unite these thrusts and cause their resultant to act only just upon these isolated points. Hence it was of the utmost importance that the transverse and the diagonal arches should intersect in such a way that: First, the resultant of their thrusts should be converted into a single pressure at the point where

the top of the flying-buttress touched; Second, that no portion of the thrust might be able to act without, or by the side of that resultant; in a word, so that the collection of thrusts might be directed accurately in one and the same line of pressure at the moment of meeting the flying-buttress as an obstacle.

Vaults whose skew-backs were arranged according to Figure 46, could not attain this result absolutely, for their thrusts must be and, in fact, are scattered, and do not exactly unite in a resultant whose direction and strength can be exactly determined. But if, instead of these first voussoirs set with indifferent success beside one another on the abaci of the capitals, and occupying a broad surface but without any solidarity among them, we suppose a skew-back made in a single course, and if we arrange the starting-point of the arches in such a way that they will entirely intersect and make one single abutment instead of three, we shall have taken a step forward, for the resultant of the different pressures will act upon a single piece of stone, which alone will need to be made immovable. But if, again, not content with this first result, having crowded the starting-points of our arches into as small a group as possible, we consider the skew-backs only as corbel courses, and if we should place several of these courses or skew-backs one upon another with their beds horizontal until the development of the curves of each of these arches permits us to disengage their voussoirs from that mass at the base of operations, then we shall be certain of having at the base of our vaults a resultant of pressures acting along a line whose point of departure, strength and direction we cannot precisely estimate; furthermore, we shall feel assured that the top of the flying-buttress will rest, not upon a masonry without unity and without strength, but against a rigid construction presenting a homogeneous surface, as would be the piece of timber against which one rests the end of a prop. But we have made progress; in the first place, we have recognized that the diagonal arch vaults with two compartments, that is to say, upon a square plan whose diagonals are cut by an intermediate transverse

arch, oblige us to give to the vaults a very convex shape, which makes it hard for us to lay the centering; for the diagonals of the square being much longer than one of its sides, these diagonals, serving as diameters for the diagonal arches, raise their key-stones above the plane of starting to a height equal to half this diameter (see Figs. 20, 20*b* and 21), a height that the key of our transverse arches cannot attain, unless these arches be made very acute.

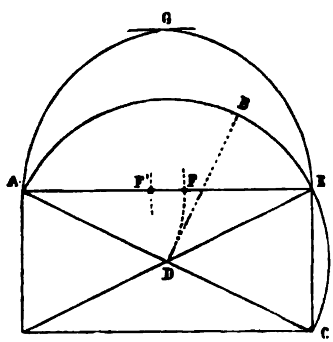


Fig. 48.

About 1230, then, they gave up this kind of vault upon a square plan, and established the diagonal arches of the naves upon an oblong plan, or, in other words, each compartment had its complete vault. We can thus make the keys of the diagonal, transverse and wall arches reach the same level or nearly so. The builders, wishing to have skew-backs with horizontal beds and reaching to the very point where these arches cease to intersect, observe that the simplest method to prevent any difficulties in drawing the outline of their skew-backs, consists in giving the diagonal and the transverse arches the same radius. Given a vault upon an oblong plan (Fig. 48), in which the diagonal arch *A C* (in plan) is a semicircle *A B C;* if we carry the semi-diameter *A D* around upon the base-line of the transverse arch *A E*, we obtain at *F* the centre of one of the branches of the transverse arch, and we draw the arc *A G*, which possesses the same radius as the arc *A B C;* laying-off the distance *A F* from *E* to *F'*, we obtain at *F'* the second centre of the transverse arch, and we draw the second branch *E G*. It is thus that the arches of the first Gothic vaults upon an oblong plan are drawn.[1]

[1] It will be remarked, in fact, that these first vaults are rather flat, compared

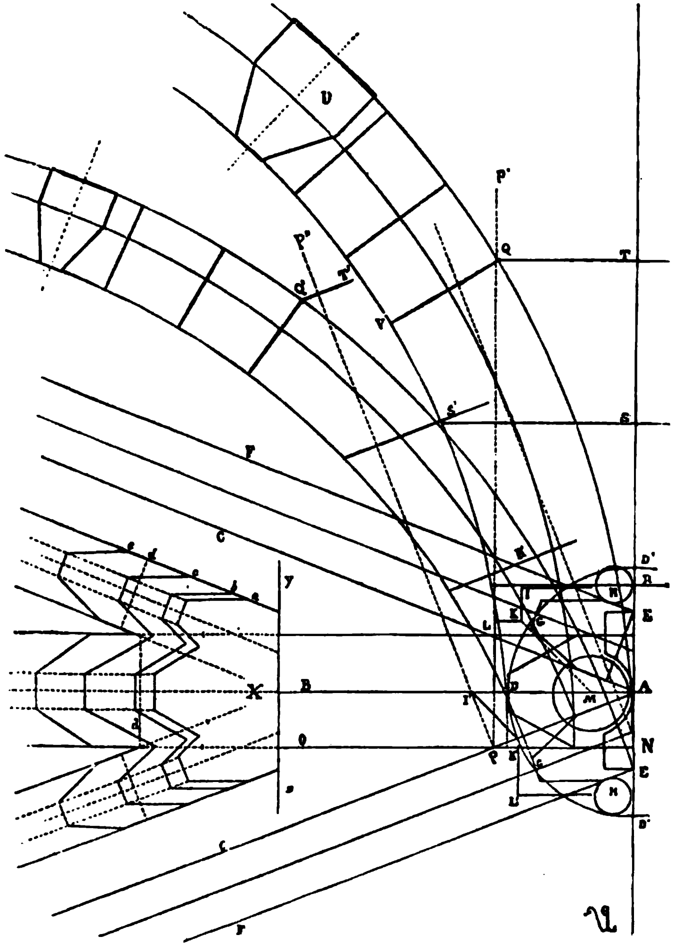


Fig. 48b.

with those of the middle of the thirteenth century, and that their transverse arches are almost semicircular. Later these vaults appeared not solid enough; so they made the diagonal arches more acute, or rather, raised their starting point, in order to be able to raise the keys of the transverse arches.

Then the curves of the diagonal and transverse arches being the same, their cross-sections are similar, and their skew-backs present no difficulty of outline.

Let us now see about outlining these skew-backs.

Let *A B* (Fig. 48*b*) be the directrix of the transverse arch and *A C* the directrices of the diagonal arches.

A is fixed at the surface of the wall.

From this point *A*, taking upon the line *A B*, a distance *A D* equal to the thickness of the voussoir of the transverse arch, and considering *A D* as a radius, we describe the semicircle *D′ D D′*.

We then trace the section of the transverse arch upon the horizontal plan.

We draw two parallels, *E F*, to the directrices *A C* of the diagonal arches, leaving between these parallels a space equal to the width of the voussoirs of the diagonal arches. These are the horizontal projections of the diagonal arches.

Taking the points *G* at the meeting of the axis of the diagonal arches with the semicircle *D′ D D′*, as the intrados of the diagonal arches, we draw the section of these diagonal arches upon the horizontal plan.

We have then the lower bed of the first skew-back. In the vacant spaces that remain between the semicircle *D′ D D′* and the diagonal arches at *H*, we place the pillars which are destined to carry the wall-arches.

The contour of the lower bed of the first skew-back having been obtained, we can draw (and only now) the abacus of the capital, whether in a re-entrant square, as indicated in *I K L*, or in star form, as indicated in *I′ K′ L′*.

Under these abaci one can put only a single capital and a single column *M*, since our intention is to unite the arches as far as possible in a close group.

This capital, which is a console, a stone corbel supported by the detached column, sends out three corbels from a single astragal.

We must project in elevation the transverse arch upon the line $N\ O$, and the diagonal arch upon the line $A\ C$.

It is clear that these two arches will cease to intersect at the point P upon the horizontal projection. From the point P, erecting a perpendicular $P\ P'$ to the line $N\ O$, the base of the transverse arch, and a second perpendicular $P\ P''$ to the line $A\ C$, the base of the diagonal arch, that first perpendicular $P\ P'$ will meet the extrados of the projected transverse arch at Q.

This point Q shows then, the height at which the transverse arch is disengaged from the diagonal arch. It is the level of the bed of the last skew-back.

It is necessary to divide the height $P\ Q$ into a certain number of courses, according to the height of their faces. Let us suppose that three courses are enough; the upper bed of the first skew-back will be at R, the second at S, and that of the third at T. At Q, the arch disengages itself and we can draw the first section $Q\ V$ tending toward the centre of the arch. Starting from this point, the voussoirs, whose section is drawn in U, are independent. It will be sufficient to proceed in the same way with the diagonal arch, by drawing the beds $R'\ S'\ T'$, beginning at the base-line $A\ C$, as far apart from one another as are the beds $R\ S\ T$. The diagonal arch being less thick than the transverse arch, there will remain behind its extrados at Q', up to the point of intersection with the extrados of the transverse arch, a little space of horizontal bed that will be very useful for beginning to lay the filling-stones of the triangles of the vaults. This done we can give up to the head workman each of the beds of the skew-backs, drawing off upon a horizontal plan, as out-lined in X, the sections that the beds $R\ S\ T$ and $R'\ S'\ T'$, give in the projected arches.

Then we obtain: 1st, at a the lower bed of the first skew-back, already drawn as the origin of the arches; 2d, at b the upper bed of the first skew-back, which gives the lower bed of the second; 3d, at c the lower bed of the third skew-back; 4th, at e the upper bed of

this third skew-back with its bent sections marked at *d*. There is no need to say that at least the first two of these skew-backs, if not all of them, are fastened at the rear into the wall whose surface is *Y Z*. Should we wish to crowd the diagonal arches still more against the transverse arch, it would suffice, in beginning the work, to bring the axis of the diagonal arches, on the horizontal plan, nearer to the point *A*. Often these axes even meet at the point *A*. In order not to complicate the figure uselessly, we have supposed the arches to be plainly moulded; but if they are made with elaborate mouldings we should proceed in the same way upon the working-drawing, except in outlining the contours; for it is necessary to know, upon the different horizontal beds of the skew-backs, the sloping sections which are made upon these contours, in order to furnish the stone-cutter with moulds which provide for the more or less perceptible change of form of the mouldings at each bed.

To make intelligible, even to persons who are not familiar with descriptive geometry, the operation that we have just described, let us suppose (Fig. 48*c*) the three skew-backs of the preceding figure to be seen one above another in perspective and with their mouldings.

At *A* we see the first skew-back, at *B* the second, at *C* the third with its sections normal to the curves of the arches, at *D* the voussoirs of the transverse arches, and at *D'* those of the diagonal arches separated from the skew-backs and henceforth similar to one another as far as the keystone.

It sometimes happens that the arches of a vault are of very unequal diameter, or that they start from different heights; this cannot trouble the workman in any respect, for at the point where one of these arches disengages itself from the others at the extrados, he makes a section normal to its curve and the voussoirs are laid in, while the other arches beside it can still remain united up to a certain height, and keep the beds of the skew-backs horizontal.

Thus, for instance (Fig. 49), let us suppose that we have to vault a hall divided by a row of piers, whose plan at one of its extremities

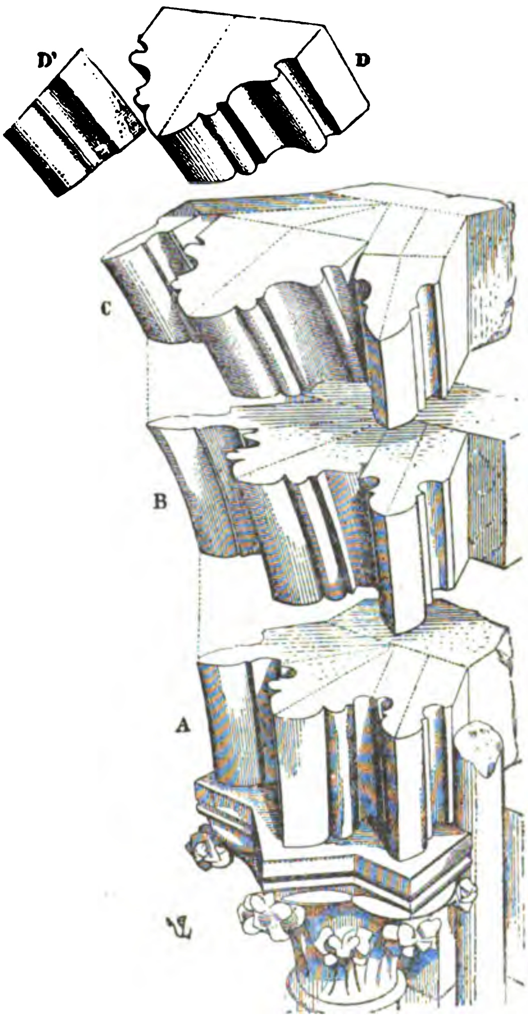


Fig. 48c.

gives us, between the piers A and B, a space much larger than that remaining between the pier B and the wall $C\,D$. Hence we shall have diagonal arch vaults, just as our figure indicates.

We project the transverse arch, $E\,F$, which gives us the diagonal arch $E\,G\,F$; we project the diagonal arch $E\,I$, which gives us the slightly broken arch $E\,H\,I$: we project the diagonal arch $K\,L$, which gives us the semicircle $K\,L\,M$; and lastly project the transverse arch $P\,N$, drawing this arch in such a way that its key may be a little below the level of the key of the diagonal arch $K\,L$, and that its curve may be almost semicircular, in order to lead the eye, without abrupt changes of level, from the great vaults included between A and B to the narrower and lower vaults included between the pier B and the wall $C\,D$.

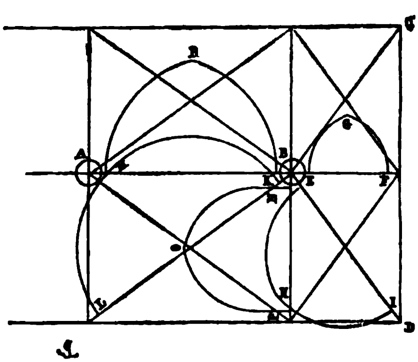


Fig. 49.

It is desirable, accordingly, to raise the origin of that transverse arch $P\,N$ still higher. It is projected in $P\,O\,N$. It is this need of avoiding abrupt changes of level in the different arches which has made us raise somewhat the key of the diagonal arch $E\,I$ above the semicircular. It is seen thus that from the great transverse arch included between the pier B and the wall the keys R, M, O, H, and G, whether of the transverse or the diagonal arches, are successively lowered by an almost imperceptible transition in their execution.

We must now imagine the skew-backs of the various arches upon the capital of the pier B, and in Figure 49*b* we present the forms of these skew-backs. At A is the skew-back of the transverse arch marked $E\,F$ upon the preceding figure; at B the second skew-back

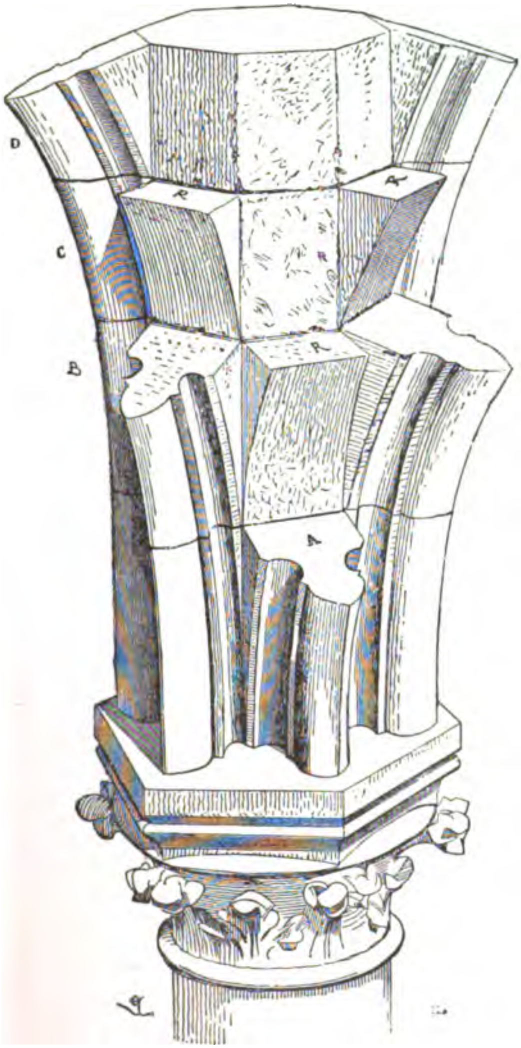


Fig. 49b.

with the two sections of the diagonal arch $E I$; at C, the third skew-back whose upper bed is entirely horizontal; and at D, the fourth skew-back with the sections of the two transverse arches $P N$, of the two diagonal arches $K L$, and of the transverse arch connecting the pier A with the pier B. One will notice the supports R which are left in the courses of the skew-backs, behind the free voussoirs, to receive the stone filling of the vaults. We have then: the first skew-back, bearing the section of one arch; the second skew-back, bearing the sections of two arches; the third skew-back, with horizontal upper bed, bearing no sections; and the fourth skew-back, bearing the sections of five arches.

These methods give much liberty to the builders, and there is no surface, however irregular it may be, that cannot be covered with ease. More than that, the system of vaults with diagonal arches allows the vaulting of halls, whose openings for instance, are taken at very different heights, or the building of vaults very much inclined.

For instance, let us suppose a hall (Fig. 49*c*) whose perimeter is the quadrilateral $A B C D$. We must make upon the side $A B$ a clear space ten metres high, without raising the keys of the wall-arches upon the sides $B C$ and $A D$ to more than six metres or the key of the wall-arch upon the side $C D$ to more than four metres.

The side $C D$ being eight metres long, upon that side $C D$ we shall outline a semicircular wall-arch whose starting-point shall be fixed on the very ground; and on the other sides we shall outline our wall-arches as we may prefer, whether pointed or semicircular.

Dividing the four lines $A B$, $B C$, $A D$, $D C$, each into two equal parts, we connect the middle points G, H, I, K, by two lines whose meeting at F gives the horizontal projection of the key of the pointed or diagonal arches.

Erecting the vertical $F E$, we take upon that line the height at which is to be placed the key L, and then we draw the circular arcs $A L$, $B L$, $C L$, $D L$, which are the half arches whose horizontal projections are on $A F$, $B F$, $C F$, $D F$.

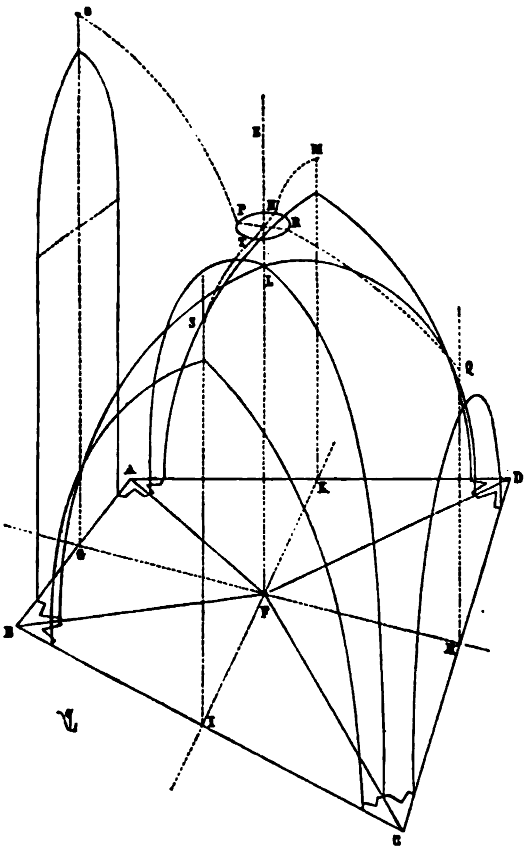


Fig. 49c.

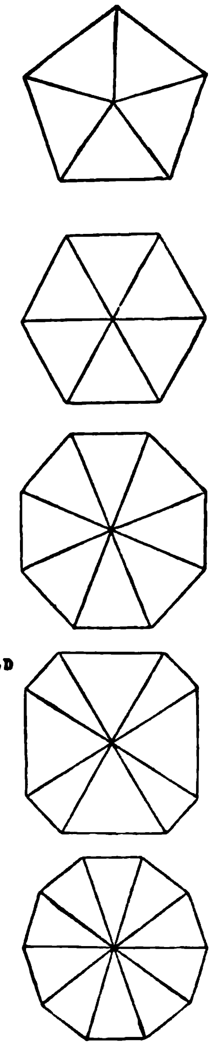


Fig. 50.

Upon the frame-work of the wall-arches and the diagonal arches, there is nothing else to do beyond making the fillings of the vaults, whose intersections or keys are represented by the dotted lines *M N*, *O P*, *Q R*, *S T*, account being taken of the thickness of the voussoirs of the diagonal and the wall arches, and the central key being supposed to be fixed.

But we shall at once attend to these fillings and the manner of making them. Whatever be the plan of the surface to be covered, the problem to be solved is always this: First, to cause this surface to be divided by the diagonal arches so as to present a series of triangles, for with this system of vaults, one can cover only triangles;

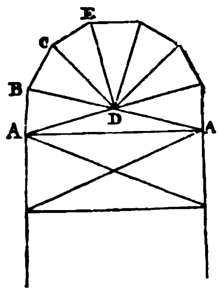


Fig. 51.

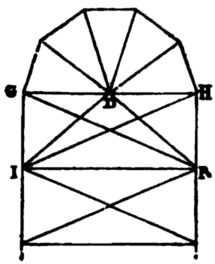


Fig. 51 *b*.

Second, to arrange the diagonal arches (ogives) in such a manner that these arches buttress one another reciprocally at their summit, and that one or more of them cannot press upon the others so as to put them out of shape.

Thus, to cover a hall in the shape of a polygon, of five, six, seven, eight, ten or twelve sides, or even more, it is naturally sufficient to connect the inner angles of the polygon by lines meeting in the centre, as indicated by Figure 50.

These lines are horizontal projections of the diagonal arches, and the sides of the polygons are those of the wall-arches, which may have their keys above or below the level of the central key, according as necessity directs. If it is necessary to cover a portion of a

polygon at the end of a parallelogram, as we sometimes find in the chancels of churches, for instance (Fig. 51), we shall arrange to have, in front of the broken part *B C* a compartment *A B*, equal to one of the sides of the polygon *B C*, in order that the key *D* may be equally distant from the points *B*, *C*, *E*, etc., and that the triangles *B C D*, *C E D*, may have their sides *B D*, *C D*, *E D*, all equal. In this case the arches *A D* buttress the arches *B D*, *C D*, *E D*, etc., and we always have only triangles to fill. Still there are exceptions to this rule, and one sees arches radiating from apses and buttressing their summits against the apex of a transverse arch (Fig. 51*b*), when, for instance, the apse-plan is a half of a dodecagon; but this method is a bad one, since the arches all pressing upon the unsupported key *D'* can make the transverse arch *G H* yield. In this case, experienced builders have fixed two branches *I D'* and *R D'* of a diagonal arch, destined as a powerful buttress for the key *D'*. But if these vaults can be built by means of arches whose keys are upon different levels, they can also be built upon arches of very different diameters, whose keys are all upon the same level. It is sometimes necessary to level the keys, if, for instance, the case is one of a vault having a floor above it; this case frequently occurs in porches surmounted by galleries or halls above the aisle.

The porch of the church of Notre Dame at Dijon is one of the best examples that we could choose. Its plan (Fig. 52), follows the plan of the nave and aisles of the church itself, but the central vault, instead of being higher, as in the church, has its keys at the level of the vaults of the aisles, for it is necessary to receive on the upper story a paving at the same level on the whole surface of the porch. Wishing to give solidity to the façade, the builder has doubled the piers at this point, and has built parallel transverse arches, separated by a cradle-vault, from *A* to *B*, from *E* to *G*, from *B'* to *C*, from *G'* to *H*, from *A'* to *D*, and from *E'* to *F*.

Next, the central part of the porch is covered by a vault on diagonal arches *G K* and *E I*, crossed by a transverse arch *L M*.

The aisles are vaulted with diagonal arches on a square plan. We have given upon our plan the projection of all these arches, whose keys are fixed upon this same horizontal plane. The diameters of these arches, being of very different lengths, it is impossible to have the arches start from capitals placed all on the same level. Accordingly, the capitals of the diagonal arches, *G K* and *E I* and of the transverse arches *E G*, *L M*, *I K*, are set lower than those of

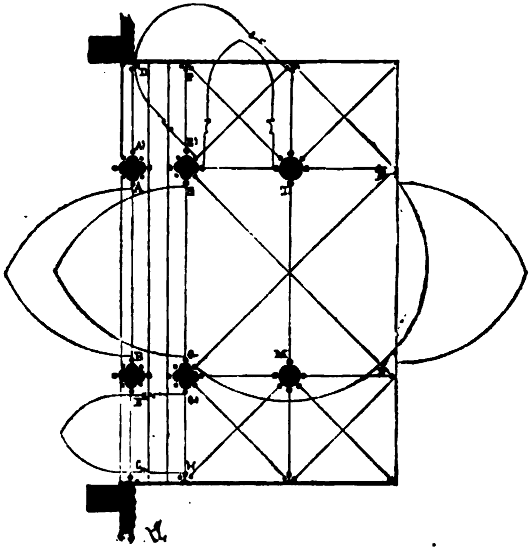


Fig. 52. Porch of Notre Dame, Dijon, France.

the arches *G M*, *M I*, *E L*, *L K* and the diagonal arches of the aisles.

If we then give a perspective view of the pier *M* (Fig. 53), we see that the transverse arch *A* starts from below the other arches and that its capital *B* conforms, by its position, to that difference of level. The drums of the pier carry the two skew-backs *C* and *D* of the transverse arch *M L* (in the plan) which disengages itself below the capitals of the other arches. As to these other arches, they rest

their skew-backs upon a group of capitals sustained by monolithic pillars. The effects of the unequal thrusts acting at different

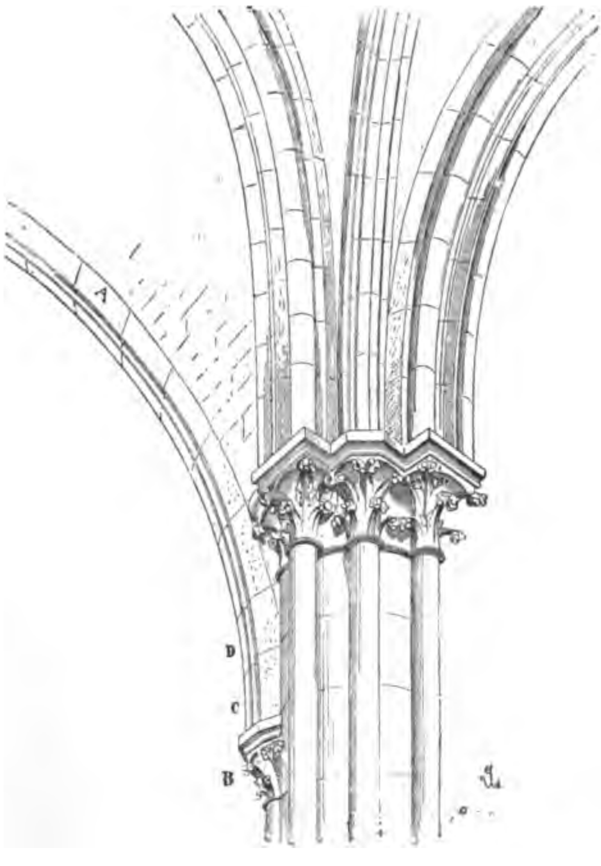


Fig. 53. From the Porch of Notre Dame, Dijon, France.

heights on the arches are neutralized by the vertical weights carried by the piers, for these weights are considerable.

As far back as the middle of the thirteenth century, in England,

they reached very skilful and highly developed combinations of arches in vaults.

The Normans quickly became clever builders and their structures of the Romanesque period are remarkable for the great independence and the exceptionally perfect execution therein displayed.

Even as early as the beginning of the twelfth century, they were building vaults with diagonal or pointed arches having projecting ribs, while in France, they built only Roman groined vaults, without diagonal arches, but having curved surfaces in every direction, as we

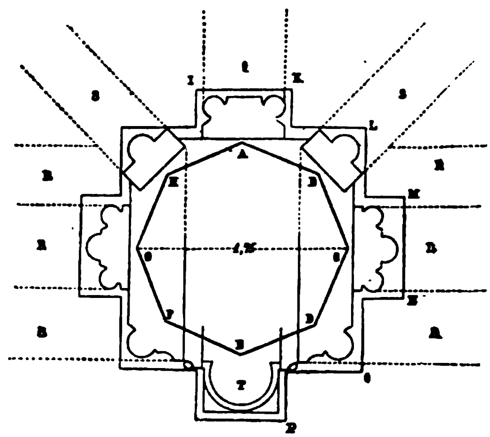
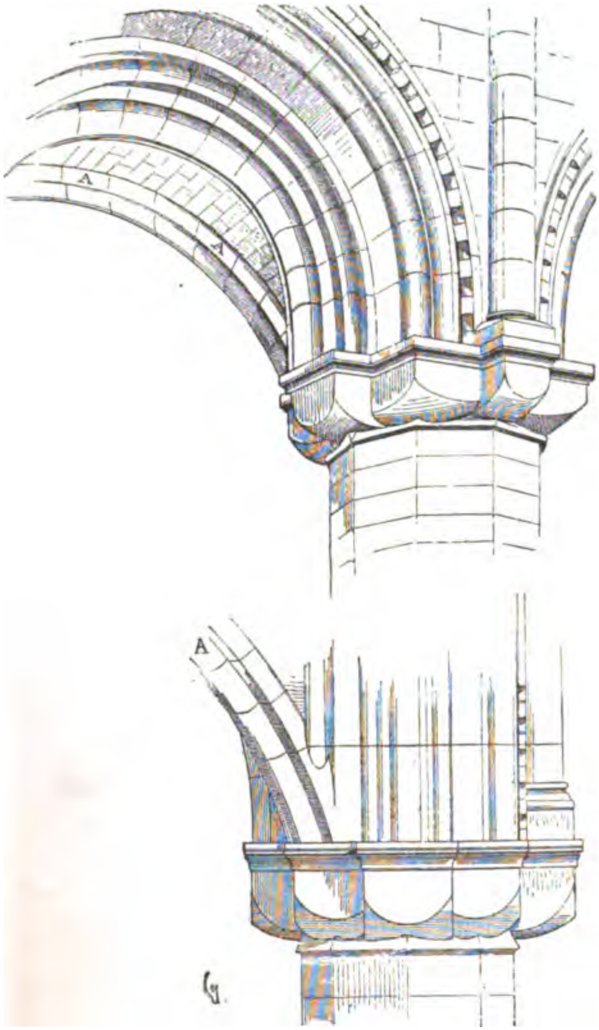


Fig. 54. Pier in Choir Aisle, Peterborough Cathedral.

have previously seen. They knew the advantage to be gained from the skew-backs and they divided their capitals, if not the vertical supports, into as many members as they had arches to maintain. Thus, in the Romanesque part of the Cathedral of Peterborough, the vaults of the aisles of the choir, which open into the transepts, are, for that period, conceived and executed with more wisdom and precision than those in the royal domain of France, in Champagne, in Burgundy, or in the central part. These vaults rest upon piers, alternately cylindrical and prismatic, set with their angles upon the axes.



Figs. 54*b* and 54*c*. Pier in Choir Aisle, Peterborough Cathedral.

The capitals extend the section of the piers to the lower bed of the various arches by means of corbels skilfully combined.

Figure 54 presents the horizontal section *A B C D E F G H* of a pier, the plan *I K L M N O P* of the abaci of the capital, the outline upon these abaci of the lower bed of the transverse arch *Q*, the archivolts *R* carrying the walls of the transept, the diagonal arches *S* and the base of the engaged column *T* which rises up to the trusses above, covering the principal interior space. In order that the keys of the diagonal arches over the aisles should not extend beyond the level of the extrados of the archivolts and transverse arches, which are semicircular, these diagonal arches are drawn upon an arc less than a semicircle.

(Fig. 54*b*) shows in perspective this capital and the terminations of the arches, while at *A* is seen a branch of a diagonal arch.

The geometrical drawing (Fig. 54*c*) explains the origin of that branch of the diagonal arch *A*, the skew-backs of all the arches and the corbels of the capital.

When we compare this structure with those that are contemporaneous with it in France proper, we are astonished at the wisdom and the experience of the Norman architects, who, at the beginning of the twelfth century, were already able to construct vaults on diagonal arches and arranged the capitals in as many members as they had arches to receive. But before following the rapid progress of the Anglo-Norman vault and exhibiting the singular results to which the architects beyond the Channel arrived, toward the middle of the thirteenth century, we must first examine the means used by French builders to close the triangles of the Gothic vaults. The general principle must precede the varieties and the exceptions.

Let Figure 55 be the plan of a vault with diagonal arches covered by a transverse arch, according to the method of the first Gothic builders, *A B* being the semi-diameter of the principal transverse arch, *A C* the semi-diameter of the diagonal arch, *A D* the wall-arch and *D C* the semi-diameter of the transverse arch cutting the tri-

angle $A\ E\ C$ into two equal parts. The wall-arch must be our first consideration.

Let us suppose the stones manageable, so that a mason can easily

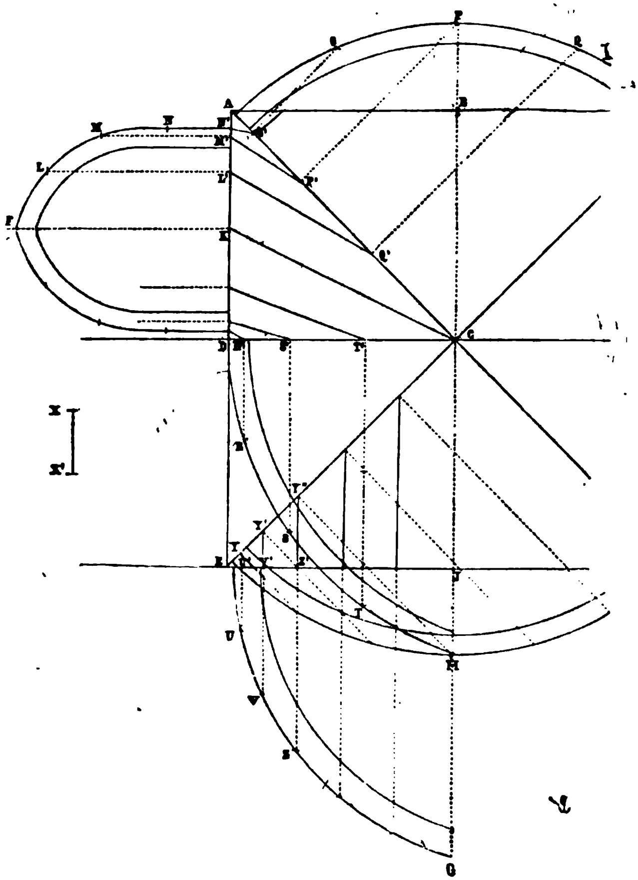


Fig. 55.

lay them by hand and let them have the width $X\ X'$ (a width varying from .08 centimetres to .15 centimetres in this sort of building).

We project the extrados of all the arches upon a horizontal plane

These projected figures give us for the wall-arch, with its stilt, the broken curve $A\ F\ D$; for the principal transverse arch, the broken curve $E\ G$; for the diagonal arch, the exact circular quadrant $A\ I$; for the intersecting transverse arch, the broken curve $D\ H$.

Let us not forget that, the diagonal arch being semicircular, the intersecting transverse arch must have a radius $C\ H$ equal to the radius $C\ I$; that, in ordinary cases, the principal transverse arch must have a radius $J\ G$ shorter than the radius $C\ I$ and that the wall-arch must have with its stilt, a radius $K\ F$ shorter than that of the principal transverse arch.

The width of the soffites of the filling being $X\ X'$, we must find out how many times the extrados of the half-wall-arch $A\ F$, including its rise, contains $X\ X'$; suppose it to be four times; then we mark the dividing points L, M, N. So we have four rows of stones.[1]

Referring the wall-arch back upon its horizontal projection $A\ D$, the point N taken upon the vertical part of the wall-arch falls on N', the point M on M', the point L on L' and the point F of the key on K. We then divide $A\ I$, the half of the extrados of the diagonal arch, into four parts and mark the points O, P, Q. Referring that curve back in the same way upon its horizontal projection $A\ C$, we obtain upon that arch the points O', P', Q', C.

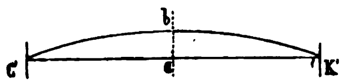


Fig. 56.

We proceed, in the same manner with the intersecting transverse arch $D\ C$, whose projected extrados is $D\ H$. We divide that extrados into four parts and mark the points R, S, T.

Revolving the arch upon its radius $D\ C$, we obtain in horizontal projection the points R', S', T', C. Then joining the point N' to the point O'; M' to P'; L' to Q', K to C, etc., by straight lines, these lines give us the horizontal projection of the vertical planes

[1] In order not to complicate the figure we suppose a very limited number of divisions of the soffite. The operation is the same, whatever be the division of the soffite.

through which the intrados sections of the end stones must pass. This being obtained, the principal transverse arch governs the number of soffites in the vaults closing the triangles *E J C.*

The standard divisor *X X'* having given us upon the extrados of the principal transverse arch, projected to *E G*, six rows of stones, we mark the points *U*, *V*, *Z*, etc., and working as before we obtain, upon the line of horizontal projection *E J* of that transverse arch, the points *U'*, *V'*, *Z'*.

Dividing in the same way the extrados of the diagonal arch into six parts and projecting these divisions upon the line of the plan *E C*, we obtain the points *Y*, *Y'*, *Y''*, etc.

We then join the point *U'* to the point *Y*, the point *V'* to the point *Y'*, etc., and we have the horizontal projection of the vertical planes through which the intrados sections of the soffites must pass.

This diagram is not made in the building-yard.

After having divided the extrados of the wall arches and of the principal transverse arches, governing them, according to the number of the soffites given by the width of the blocks, we divide into equal parts the extrados of the diagonal arches, as we have just shown, and we proceed at once to the building of the vaults without movable centres; this is the method used for giving in horizontal projections the lines *N'*, *O'*, *M'*, *P'*, *L'*, *Q'*, etc., and *U' Y'*, *V' Y'*, etc., which we have drawn upon our diagram.

Let us see in what this method consists.

The builder says, for instance: "The line *C K*, joining the key of the diagonal arches to the key of the wall-arches, will have a versed sine of .50 centimetres;" then the mason, accustomed to make this sort of vault, has no need to know more in order to build, without a diagram, the entire triangle of filling *A C D.* It is sufficient for him to take the distance *C K* or *C J* and draw (Fig. 56) *C' K'* upon a plank and then erect in the middle of this line a perpendicular *ab* of .50 centimetres and pass an arc through the three points *C' b K'*. Having the drawing of this curve with him, he builds at least one

third of each of the sides of his filling, as a wall. It suffices him to measure with a string, the length of each row of stones, and carry that length around upon the arc $C' b K'$ and then see what versed sine that chord gives for the portion of the arch so cut off; that versed sine is the one to be taken for the closing row of stones.

The first third of the filling has so nearly a vertical arrangement that the stones keep their places of their own accord, just as the mason lays them, as seen in Figure 57. But above the first third, or thereabouts, he needs the aid of a curved pattern, since the rows of stones grow longer in proportion as one approaches the key. Now, because these rows grow longer, it would be necessary to cut a templet for each of them, which would be tedious and expensive. He must accordingly have two patterns, arranged as shown in Figure 58, being longer, together, than the line of filling at the key and each alone being no longer than the row of voussoirs, too sloping to be set in without the aid of a support. Each of these patterns, cut out of a plank about .04 centimetres thick, has in the middle a slot, hollowed out, concentric to the curvature of the standard arc, of which we were just speaking (Fig. 56).

Fig. 57.

With the aid of two wedges, C, passing through these slots, we make the two patterns firm, and at every row of voussoirs can elongate them at will, by sliding them one against the other. The patterns are fixed upon the extrados of the arches, by means of two iron

angles, *A B*, nailed at the extremities of the curves; the mason must take care, after having placed the tips *A B*, upon the points marked upon the arches, to let the surface of the pattern hang vertical before fixing it to the sides of the arches, whether by pins or by a handful of plaster.

Thus the workman closes the fillings of vaults in accordance with the diagram (Fig. 55); in other words while giving to each row of voussoirs, in the filling, a sufficiently marked curve to bind them together and throw their weight upon the arches, he is none the less obliged to keep that curve vertical, for he must place his curved pattern under each line separating these rows of stones as seen in Figure

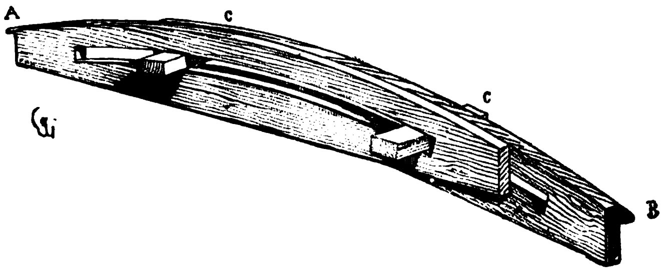


Fig. 58.

59 and not under the middle of these rows themselves. It is not without reason that they must place the patterns in a vertical plane and, thereby cause the edge of the bed of each row of stones to pass through this vertical plane.

These beds (Fig. 60) on the intrados being curved, it results that the section *C D* is found to have a greater development than the section *D B* which governs the number of rows of stones and even then the section *D A*, although in horizontal projection the line *D A* is longer than the line *D C*. The mason must take account, at each row of stones, of this excess of development and give to each of these rows a soffite presenting the surface drawn in *E*. The workman then, must be guided by a mechanical device: for the curved

pattern, always set vertically, gives necessarily the form to be given to the soffites. If the mason closed the fillings with rows of voussoirs whose soffites were of equal size throughout all their extent, he would be obliged, on reaching the key, to account for the surplus of development given by the section $C D$ over the section $D B$ and he would have two final rows of stones presenting on the intrados a surface analogous to that represented in G, which would have an unpleasant effect and would oblige him to employ, at this point, stones of much larger size than anywhere else. Being obliged, through the vertical position of the curved pattern, to make the inner edge of the bed of each row of stones keep within a vertical plane, the mason succeeds unconsciously in distributing among all these rows the surplus of development caused by the concavity of the vault.

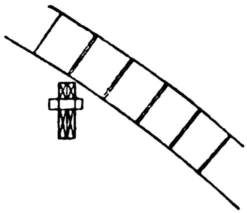


Fig. 59.

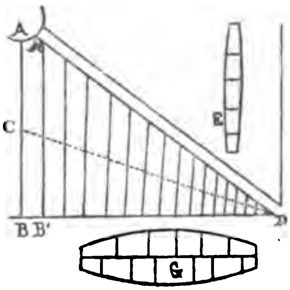


Fig. 60.

All this is much simpler to execute than to explain and we have never found any difficulty in adopting this method in practice.

A skilful mason, aided by a boy who brings him the required stones and mortar, can cover the triangle of a vault without the aid of any machine, without centering and without other tools than his hatchet and templet. When once the workman has understood the structure of these vaults (which does not take long) he lays the rows of voussoirs with great ease, having only to touch them lightly with his hatchet in order to prevent their parallelism. Almost always when he has acquired practice, he gives up the slot patterns and

contents himself with two curves that he fastens with two pins, lengthening them at every row, for the beds of these stones being very little inclined, except near the key, a slight support is enough to hinder them from slipping on the mortar. Each row when set forming an arch, the pattern is taken away, without causing the least movement.

It must be said that these stones are seldom very thick and that many fillings in great Gothic vaults, especially at the end of the twelfth century, have no more than from 10 centimetres to 12 centimetres of thickness.[1]

This method of building the vaults is not the only one; it belongs only to Ile-de-France, the district about the city of Beauvais and Champagne, during the second half of the twelfth century, while in other provinces less rational means are adopted. In Burgundy, thanks to special kinds of limestone, composed of thin courses with rough surface and adhering firmly to mortar, they for a long time built their vaults of ~~plastered~~ masonry, filled-in over wooden centres.

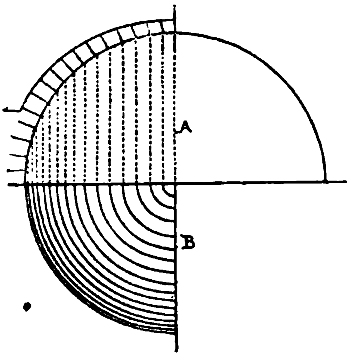


Fig. 61.

The chancel vaults of the abbey church of Vezelay, built toward the end of the twelfth century, present a singular mixture of the methods adopted by the builders of Ile-de-France and of Burgundian traditions. One sees how much the Burgundian workmen, skilful draughtsmen as they were, were perplexed about giving the voussoirs of their filling the proper shapes; unable to make the exact drawing, they experimented wildly, making the haunches of the vaults of materials cut as best they could; then,

[1] The fillings of the great vaults in the Cathedral of Paris have only 10 centimetres of thickness.

not knowing how to close these fillings, they finished them off with rough stones plastered over.

This was not a method, but a make-shift.

In the midst of the provinces comprised in ancient Aquitania, the habit which the builders of the tenth and eleventh centuries had contracted of closing their structures with domes was so deeply rooted that they did not until very late understand the Gothic groined vault, and adopted its appearance, but not its true structure.

Every one knows that the voussoirs composing a dome give, in horizontal projection, a series of concentric circles, as Figure 61 shows. *A* being the cross-section and *B* a quarter of the horizontal projection of a hemispherical dome.

When the Gothic system of construction prevailed in the royal domain and when architects saw the advantage to be derived from it, they at once wanted to adopt it in all the western provinces of the Continent. But these various provinces, although attracted by the form, the bold procedure and the facilities offered by the new architecture for overcoming obstacles hitherto insurmountable, could not tear themselves abruptly away from the traditions so powerfully rooted among the builders and there resulted a sort of compromise between structure and form. In the twelfth century we see arising, all along the line reaching from Perigord to the Loire, at Angiers and beyond, vaults which in structure are true domes but which try to simulate the appearance of groined vaults. These are domes under which two diagonal arches have been built, rather as a concession to the taste of the time than as a requirement for solidity; for, in fact, these diagonal arches, generally very weak, support nothing, but often are even attached to the fillings and maintained by them. This fact is of great importance, for we shall soon see what were its consequences. Nevertheless, these builders of domes soon saw that the structure of their vaults was by no means in harmony with their apparent form. The tendency was already impressed upon nearly the whole of present France by the end of

the twelfth century; people had to submit to the mode of construction invented by the artists of the North; they must abandon Romanesque traditions, which were worn out and which the people rejected as insufficient for their needs and as the living expression of that monastic power against which the national spirit was rising. The schools that were submissive to the dome made a first concession to the new mode of construction; they understood that the diagonal (ogive) arches were built in Gothic structures to carry the fillings, so instead of laying rows of filling-stones, as they had done at first, regardless of the diagonal arches, as indicated in Figure 62, they took the extrados of these diagonal arches as a base of support and laid the rows of stones, not from the transverse or wall-arches toward the diagonal arches, like the builders in Ile-de-France, but from the diagonal arches to the transverse and wall arches, intercrossing them at the key.

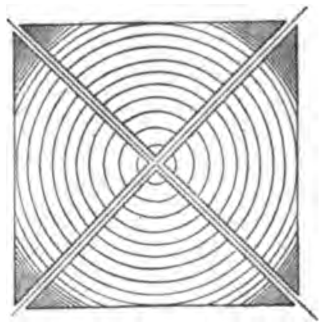


Fig. 62.

Figure 63 will explain this arrangement.[1]

This construction was less rational than that of the northern vault, but it gave the same section; that is to say, from *A*, the key of the transverse or wall arches, to *B*, the key of the diagonal arches, the triangular fillings *A B C* form a re-entrant angle, a hollow groin. But since these meetings *A B* of the rows of stones, produced a bad effect and offered a difficulty to the mason, who needed at that line *A B* a wooden curve to support each row of stones while he laid them, they stretched a rib of stone from *B* to *F* to hold the ends of the rows of stones and to conceal their seams.

[1] Vaults of the cloisters of Frontfroide, near Narbonne; of the aisles of the Cathedral of Ely; of the cloister of Westminster (England); and of the aisles of the Church of Eu.

At the end of the twelfth century, Aquitania was Anglo-Norman, as well as Maine and Anjou. This system of vaults not only prevailed in these countries, but even crossed the channel and was adopted in England.

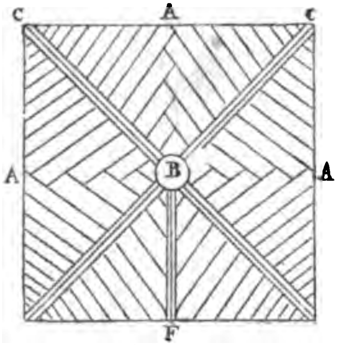


Fig. 63.

Little by little, during the first years of the thirteenth century, they abandoned it in the provinces on the Continent, in order to adopt finally the mode of Ile-de-France; but in England it remained, spread, became improved and soon led the builders into a system of vaults opposite in principle to the French system.

The manner of laying the rows of filling-stones of vaults upon the arches, borrowed in Ile-de-France from the Roman groined vaults, and in England from the dome, had singular results.

In France, the surfaces of the fillings always remained concave, while in England they ended by being convex on the intrados, or rather by forming series of reversed curvilinear cones intersecting and by generating forms quite opposed, therefore, to their origin.

But when one studies Gothic architecture, he soon recognizes that the reasoning, the logical consequences of a principle once admitted proceed with inflexible rigor, even to the production of results apparently very strange, extravagant and far removed from the point of departure. To him who does not lose the traces of the incessant attempts of the builders, the transitions are not only perceptible, but logically deduced; their onward movement is irresistible: but they appear to be the result of caprice, if for an instant one drops the clue. Moreover, no one should accuse those of disloyalty who, not being builders, judge what they see without understanding the origin and the meaning; what we can reproach them

for, is the wish to impose their judgment upon others and to blame the artists of our time who think that they find, in this long labor of the human mind, resources and useful teaching. Every man can express his opinion upon a work of art, by saying: "This pleases me," or "This does not please me"; but no one is permitted to judge a product of the reason otherwise than by reasoning. It is free to every one to deny that a perpendicular let fall upon a straight line forms two right angles; but to wish to hinder us from proving it and, above all, from recognizing it, is to carry the love of ignorance too far.

The Gothic architecture may fail to please by its form, but if any one claims it is only the product of ignorance and chance, we shall ask leave to prove the contrary and having proved it, to study and make such use of it as may seem best to us.

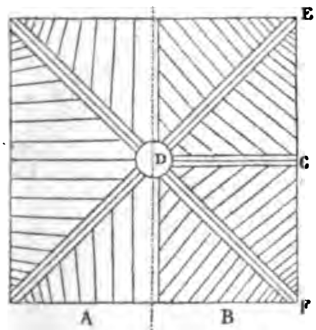


Fig. 64.

Accordingly, before closing this chapter on vaults, let us see how the Anglo-Normans transformed the dome of the West into a vault very far removed in appearance from the hemispherical vault. We have just told how the builders of Aquitania, Anjou, Maine and England had been induced to add a rib to the diagonal-arch vault, to hide the crossing of the filling-stones under the line of the keys; or, in other words, how they divided a square or oblong vault into eight triangles, instead of four. This point of departure has so great an importance that we ask leave of our readers to insist upon it.

Let us suppose a diagonal-arch vault made half by Frenchmen at the beginning of the thirteenth century and half by Anglo-Normans.

The French vault will give (Fig. 64) in horizontal projection, the drawing *A*; the Anglo-Norman vault, the drawing *B*.

Hence nothing was more natural, than to connect *C*, the key of the wall-arch, to *D*, the key of the diagonal arches, by a projecting rib, hiding the seam formed by the meeting of the triangles of filling-stones *E C D*, and *F C D*.

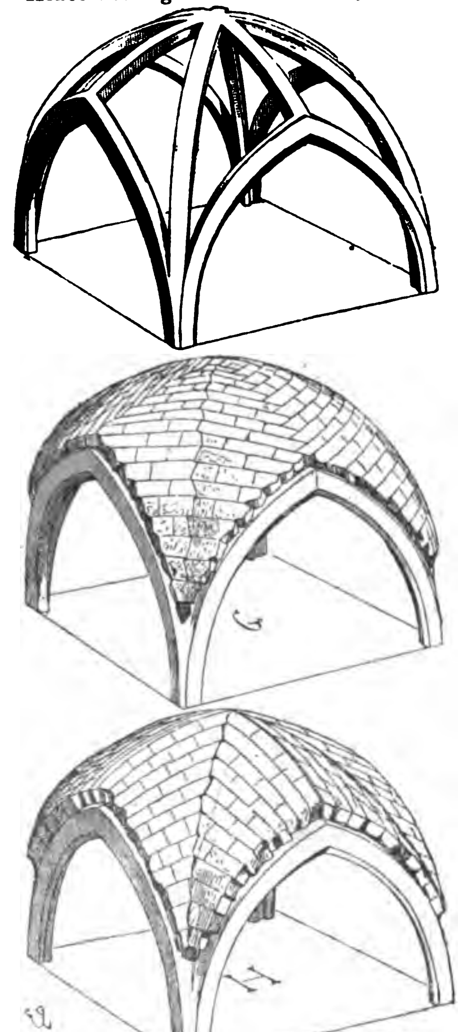


Fig. 65.

These triangles of filling are evidently derived from the dome, or, rather, they are four pendentives which meet in *C D*.

The vaults of Aquitania, or the early Anglo-Norman Gothic, have also the keys of their wall-arches on a lower level than those of the diagonal arches and their framework is presented in Fig. 65.

This figure clearly shows that the Anglo-Norman vault is only a hemispherical dome, intersected by four pointed arches, for the diagonal arches are semicircular.

Upon this framework the rows of filling-stones are laid, as represented in *G*, while

in France upon two diagonal and four wall-arches of the same dimensions and shape, the rows of filling-stones are arranged according to the drawing *H.*

Then, although the principal ribs of vaults in France and in England may be identical in outline, in France the filling is evidently derived from the Roman groined vault, while in England it is taken from the dome.

Up to this point, though the principles of the construction of these two vaults are very different, their appearance is the same, save for the addition of the rib joining the keys of the transverse or wall arches to the key of the diagonal arches, an addition not absolutely the rule.

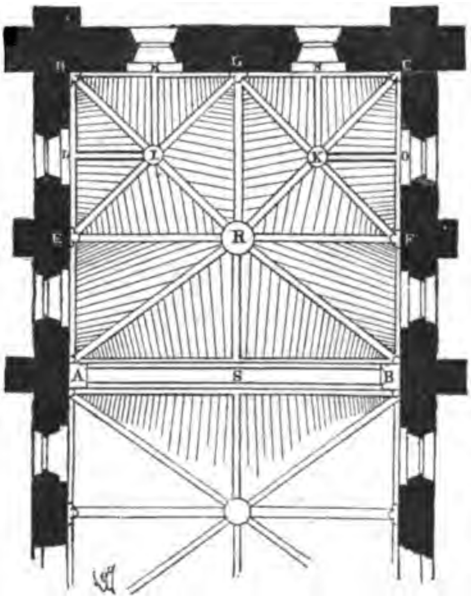


Fig. 66

While in Ile-de-France and the adjoining provinces, at the end of the twelfth century, they were making only vaults with diagonal arches, crossed by transverse arches, or, in other words, always engendered by a square plan and closed by sloping spandrel filling, as seen in Figure 55, they were seeking in the West to obtain the same real and apparent lightness, but always while keeping something of the dome.

There exists near Saumur, a little church, which indicates in the

plainest way, the wavering of the Western builders, between the innovations of architects in the royal domain and the traditions of Aquitania:—it is the Church of Mouliherne; there the two systems confront each other.

The first bay of this church with a single nave reaching to the façade, is vaulted according to the plan Figure 66.

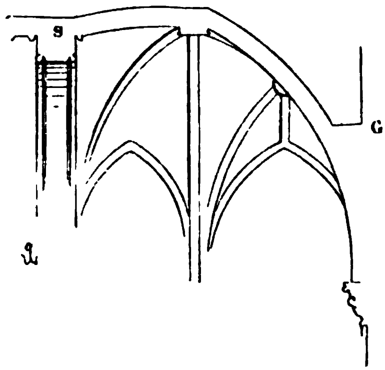


Fig. 67.

From *A* to *B* is a large transverse pointed arch.

From *A* to *C* and from *B* to *D* are two broken pointed arches, which are only mouldings with semicircular section.

A second transverse arch *E F*, of similar section, crosses the two diagonals.

From *E* to *G* and from *F* to *G* are stretched two other secondary diagonal arches, meeting the principal diagonal arches in *K* and *I*.

The four triangles included between the points *E*, *F* and *G*, are closed, according to the Aquitanian or Anglo-Norman method, that is to say, according to the principle of the dome; the four other triangles, *E D I*, *D G I*, *G C K* and *C F K*, are closed according to the French method and yet the ribs *L I*, *M I*, *N K* and *O K*, joining the keys of the wall-arches to the meeting-points *I* and *K*, project below the rows of the keys of the fillings. These ribs are even adorned with figures carved in relief.

As to the triangles *A E R* and *B F R*, they are closed in the French way by slanting fillings. But as half of a transverse arch exists from *G* to *R*, the builder has felt it his duty to continue it as a projecting key rib, up to the summit of the great transverse arch *A B*.

Thus the section taken through *G S* gives the drawing (Fig. 67). If one wishes to get an exact idea of the appearance of this vault, he must refer to the perspective view which we give in Figure 68.

In the royal domain they would have been content to close the

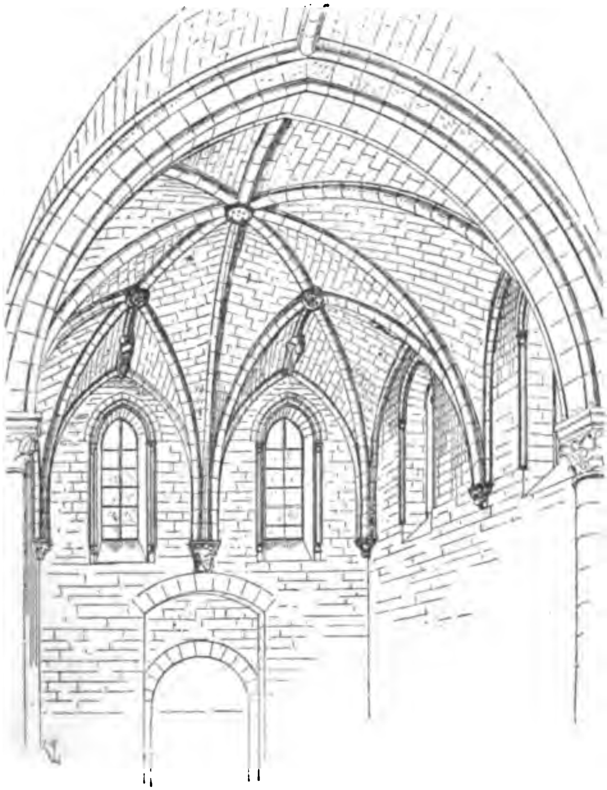


Fig. 68.

triangles of filling (Fig. 66), *E D R*, *D G R*. *G C R*, *C F R*, by rows of stones laid from the wall-arches *E D*. *D G*, etc., to the transverse and diagonal arches *E R*, *G R*, *D R*, just as they have done with the triangle *A E R*.

So long as the Aquitanian and Anglo-Norman vault kept its diagonal arches very high, like those of the early French Gothic vault, the appearance of these vaults was almost the same; but in

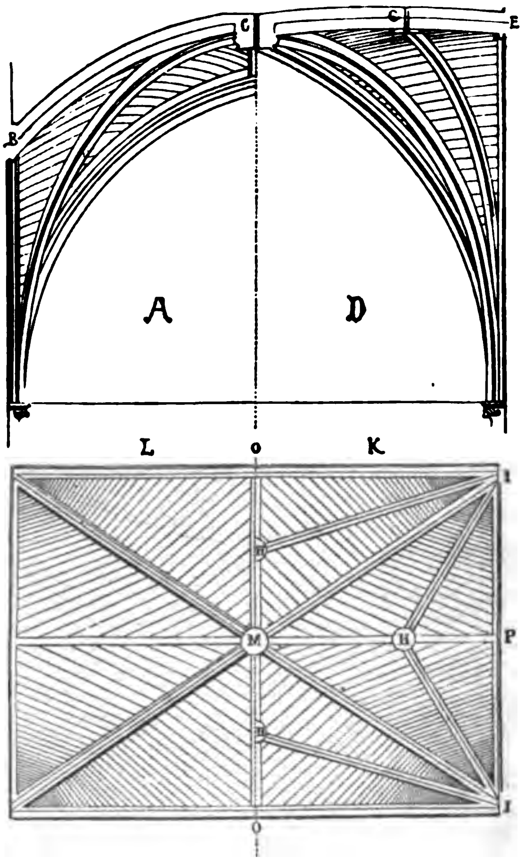


Fig. 69.

France they saw, from the end of the twelfth century, the advantage that there would be in raising the keys of the transverse and wall-arches to the level of the keys of the diagonal arches; first, in order

to be able to make the windows higher; second, to let the tie-beams of the trusses pass above the vaults without immoderately raising the lateral walls.

They wished to copy this improvement in the Anglo-Norman provinces. There a difficulty was presented: the principle of construction of the rows of filling-stones derived from the dome was ill-adapted to this innovation. We have just said that a rib had to be placed under the meeting of the ends of these rows of stones.

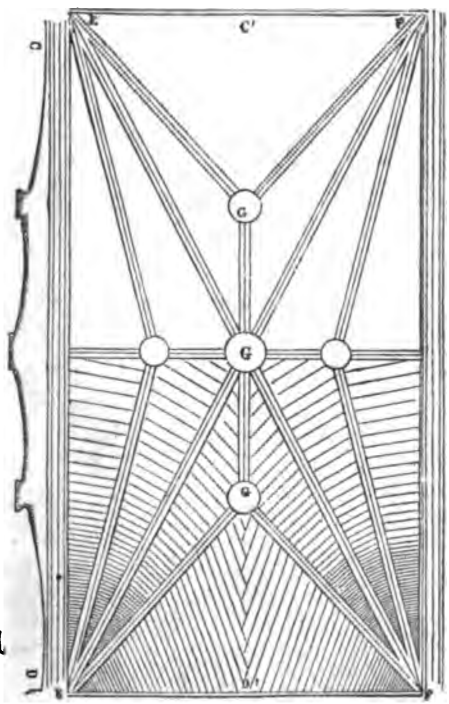


Fig. 70.

Now, let Figure 69 be the section of an Anglo-Norman vault.

When constructed according to the drawing *A*, the rib connecting the keys *B* and *C* could offer, by its curvature a perfect resistance; but if built according to the design *D*, after the new French method, the projecting rib *C E* had not enough rise to present a sufficient resistance; if the vault was large, there was reason to fear that this rib would give way at *G*, about the middle of its length. To ward off this

danger, the Anglo-Norman builders did not abandon their method of filling; they preferred to support this weak point *G* by new projecting rib, traced on *H I*, upon the horizontal plan *K* and then instead of setting the arches of filling-stones as drawn in *L*, they placed them as represented in *K*.

In examining the quarter of a vault, *O M P I*, one sees that its inner surface, through the arrangement of the rows of filling-stones, came very near giving a portion of a curvilinear concave-cone.

Once upon this path, the Anglo-Norman builders thought no more about the French vault; they developed freely the principle that they had not originally admitted, except unconsciously; they saw in the Gothic vault only a network of arches, interlacing and supporting one another reciprocally and supporting fillings all of which showed surfaces scarcely concave.

Already, in the middle of the thirteenth century, they were building the choir of the Cathedral of Ely, whose high vaults give the horizontal projection (Fig. 70), and the section *C D* made through *C′ D′*. Relying on these crossed and counter-balanced arches they did not hesitate to raise the keys *C′ D′* of the wall-arches *E F* above the keys *G*, in order to make their windows very high, as seen in the section *C D*.

But the appearance of these vaults in the interior is very different from that of the French vaults.

We give (Fig. 71) the perspective view of one starting-point of the vaults in the choir of the Cathedral of Ely. It is seen that these arches or projecting groins give a sheaf of curves, a considerable portion of which present a concave and curved conical surface, and to render that effect more striking, the builder has taken pains to unite all these arches upon the abacus of the capitals, in a compact group, whose lower bed we indicate in *A* (Fig. 71, second), and in *C*, its horizontal section at the level *B*. But if that horizontal section forms a portion of a polygon inclining towards the branches from *D* to *E*, from *D* to *F*, which is the wall-arch, it rises

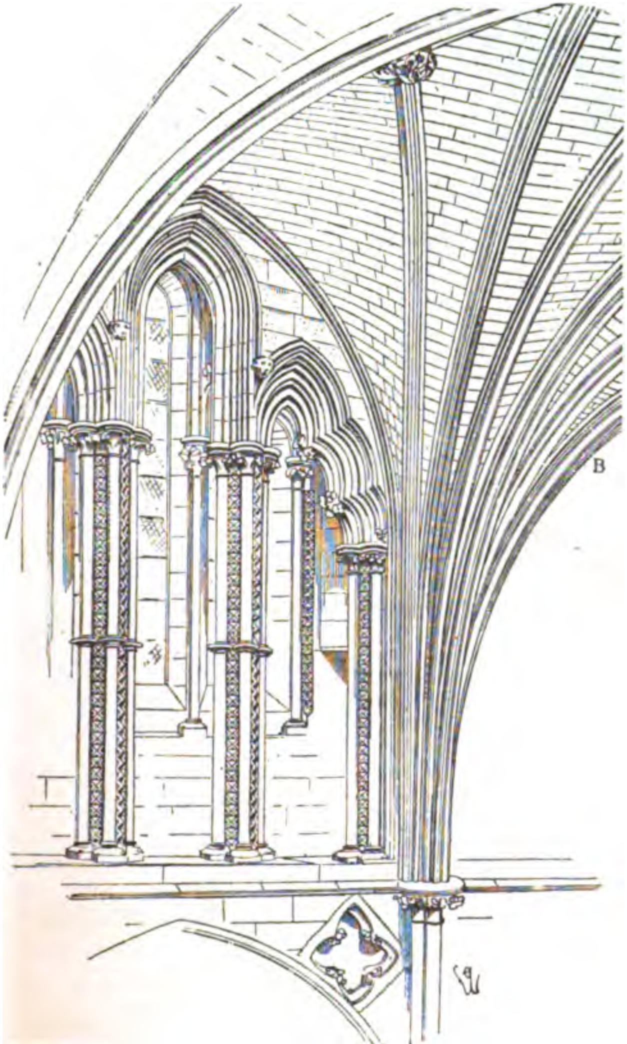


Fig. 71. From the Choir of Ely Cathedral.

(retreats) abruptly, for since the starting-point of this arch is much more elevated than that of the diagonal and transverse arches and ribs, the filling-stones *G F* must rise vertically in a plane passing through *G F*. These vaults then present, up to the starting-point of the wall-arches, a group of ribs detaching themselves from the con-

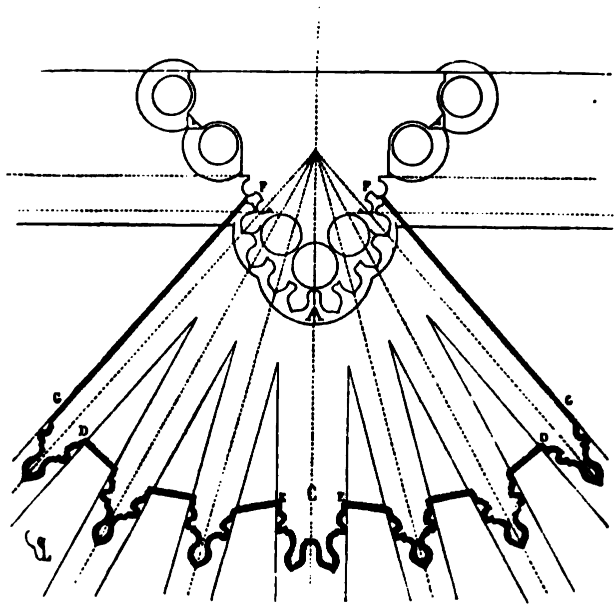


Fig. 71 *b*.

struction, a compact mass, heavy in reality, but with a certain pretension to lightness.

Wishing to keep the keys of the wall-arches on a level with the keys of the diagonal arches, as we have before remarked, and being perplexed, evidently, in their combinations, by these retreating and vertical surfaces, *G F*, the Anglo-Norman builders chose to raise the starting-points of the transverse and diagonal arches and ribs to the level of those of the wall-arches.

The presence of the vertical surfaces *F G* beside the curved surfaces *D E* was not logical enough for these *rationalists.* But while placing the starting-points of all the arches of the vault upon the same level, in order to avoid these vertical surfaces, the English architects still tried to have the keys of the diagonal and transverse arches upon the same horizontal line; so it was necessary that these transverse and diagonal arches should be very depressed. Accordingly, they came, in England, to abandon in the transverse arches the acute arch and in the diagonal arches the semicircle and to

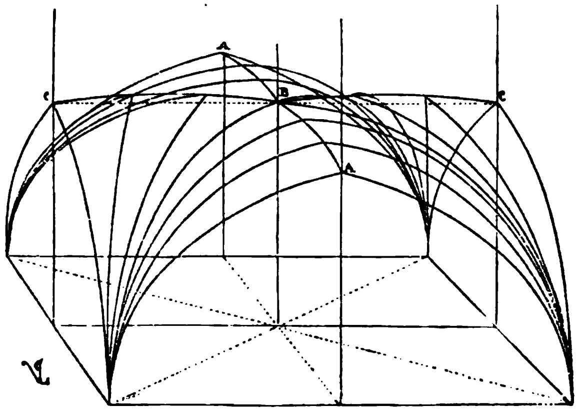


Fig. 72.

adopt curves composed of portions of ellipses, keeping the true pointed curves only for wall-arches, as indicated in Figure 72, while the keys *A*, *B*, *C*, were all in the same horizontal plane.

From these sheaves of ribs forming, as it were, pyramids, or inverted curvilinear cones to vaults composed of intersecting curvilinear cones is no great distance; and the builders at the end of the fourteenth century, in England, soon arrived at that last result (Fig. 72*b*). But these vaults are not closed by fillings of masonry upon arches faced in stone; they are vaults composed entirely of large facing-stones, very shallow, needing diagrams, a complicated

design and certain artifices such as, for example, transverse arches buried in the reversed concavities of the roof, as we have represented in *A B C*, upon the design illustrating the extrados of the vault.[1]

Thus, by a series of deductions indeed very logical, the Anglo-

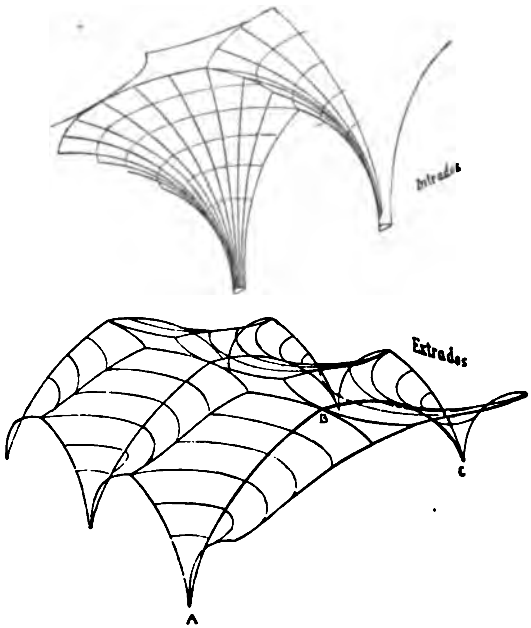


Fig. 72*b*.

Norman builders passed from the dome to the strange vaults composed of the intersections of curvilinear cones, and separated entirely from the French system.

In Normandy these vaults were never adopted, but of the English influence something remained. In that province they often abandoned, towards the end of the fifteenth century, the vaults

[1] See Dr. Willis's "*Memoirs on the Construction of Vaults in the Middle Ages*" and the translation by M. César Daly, Vol. IV of *Revue d'Architecture.*

composed of rows of filling-stones fixed upon arches. They wished also to use dressed stones.

. The Normans, the Manceaux, the Bretons willingly made vaults composed: either of large slabs of hewn stone, decorated with mouldings on the interior and mutually supported, without recourse to arches, or else of stone ceilings set upon arches. In the church of Ferté-Bernard, near Mans, there are seen pretty chapels of the sixteenth century, thus vaulted (Fig. 73).[1]

These have slabs cut in panels, on the inside, and set over pierced stonework supported by diagonal arches.

This system of construction is elegant and ingenious but one could wish here to see the windows square, for the pointed wall-arches have no longer any reason for existing.

The system of Gothic vaults had to come to this; which was necessarily its last mode of expression. To close the intervals left between the arches by ceilings, and, when necessary, multiply the arches until there were no spaces left among them which could not be filled by one or two slabs, this was to arrive at the limit of the system, and this was what they tried, often with success, at the beginning of the Renaissance, whether in religious monuments, or in civil architecture.

It is quite right to do this justice to the architects of the French Renaissance, that they knew how to employ with great freedom the Gothic methods concerning the building of vaults, and that, in breaking away from the routine by which the masters of the fifteenth century were enslaved, they applied to new forms the resources of the art of building of the Middle Ages.

At the beginning of the sixteenth century, architects very frequently employed the system of vaults composed of slabs resting on ribs, which allowed them to decorate these vaults with rich sculptures and to obtain effects until then unknown. Arranging a sort of network of stone, with key pendants or floral ornaments at the points

[1] The construction of these chapels dates back to 1543 or 1544.

of intersection of the ribs, they placed sculptured slabs between them.

Fig. 73. From a Chapel in the Church of Ferte-Bernard, near Mans.

This plan was often adopted, for instance, to cover galleries or flights of stairs with elliptical vaults (Fig. 74).

Every arch-stone of the transverse ribs A has on each side of the little key pendant a cavity B to hold the longitudinal arch-stones C; the slabs D simply rest in grooves upon these arch-stones as the detail X shows; A' is the cross-section of one of the transverse arches, B' one of the voussoirs of the longitudinal bands and D' the section of the slab. This method is simple and such a construction is good

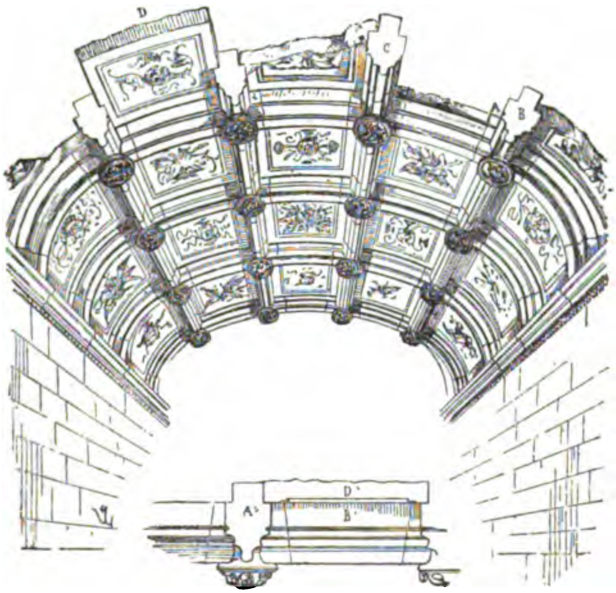


Fig. 74.

and easy to execute, as the slabs can be sculptured before being put in place; it presents all the elasticity that the Gothic builders had obtained in the composition of their vaults.

But the artists of the Renaissance forgot too promptly these excellent traditions, and if for a long time they still kept these forms, derived from a logical principle of construction, they treated these

kinds of vaults as ordinary cradle-vaults, no longer considering the cross ribs as independent ribs.

During the fifteenth and sixteenth centuries, the English and the Normans had succeeded, in the construction of vaults, in producing effects that were surprising for their ingenuity and their richness. The architects of Ile-de-France, Champagne, Burgundy and the Loire preserved, even in those latter days of the Gothic period, more moderation; and during the sixteenth century they tried to reproduce the forms, if not the structure of the Roman vault.

When the individuality of a people is left to its own inspiration and is not falsified by a narrow spirit of system, it exhibits itself with entire freedom in their works of art, particularly in those which are to a great extent the result of reasoning.

The Normans have always been daring workers rather than inventors; they have been able at all times to appropriate the discoveries of their neighbors, and therefore to derive profit to themselves. One should not require of them those efforts of the imagination, those conceptions which belong rather to the southern mind, but rather ingenious and profound applications, logical and scientific execution, persistence and care in the carrying out of details.

These qualities are found in Anglo-Norman edifices built during the twelfth and thirteenth centuries. One should not require of the Anglo-Normans that freedom of procedure, that variety, that individuality which is found in French constructions.

Among them if a method passes for a good and practical one, they perfect it, extend its consequences, follow its progress and cling to it. We, French, on the contrary, are always seeking, but we perfect nothing. The Anglo-Norman constructions are usually executed with more care than ours, but to know one is to know them all; one never sees shining out among them those original and bold inspirations which have haunted our architects from the earliest days of Gothic art; the true era of intellectual emancipation for the laboring classes of the North of France.

CHAPTER VII.

Materials.

THERE is one interesting observation to be made which may have a certain bearing. The younger nations are, the more do the monuments that they erect take the character of durability; in growing old, on the contrary, they are content with transitory constructions, as if they were conscious of their approaching end. It is with nations as with single individuals; a young man will build more solidly than a septuagenarian, for the former has no presentiment of his end and he seems to believe that all about him can last only as long as himself.

Now, the Middle Ages are a singular compound of youth and decrepitude.

The old society still keeps a breath of life while the new is in its infancy. The edifices built in the Middle Ages experience these two contrary situations. In the midst of nations permeated by a youthful and strong vitality like the Normans and the Burgundians, for instance, the constructions are built much more solidly, and assume a stronger individuality than among the dwellers on the banks of the Seine, the Marne and the Loire, whose customs during the twelfth century still bear the trace of Roman traditions.

The Burgundian even has a considerable advantage over the Norman in that he is endowed with an active imagination and that his temperament is to a degree southern.

During the Romanesque period his monuments have a character of strength that cannot be found in the other French provinces and when the Gothic system begins to be developed, he takes it up and applies it with singular energy.

Perhaps he has a less sure taste than his neighbor, the dweller on the banks of the Seine or the Marne; but he has certainly, more than the other, the feeling of his own strength, the consciousness of his own vitality and the means of displaying these youthful qualities. It seems as if the territory which he occupies had come to his aid, for it supplies him with excellent materials, of great resistance, of large dimensions and lending themselves to all the bold ideas that his ardent imagination suggests to him. On the contrary, in the basins of the Seine, the Marne, the Oise and the middle Loire, in old France, the materials furnished by the soil are soft, light and of little resistance; they ought, by their very nature, to banish the idea of temerity and oblige the builder to supply by ingenious combinations what the soil refuses to him.

We must take account of the properties of these different materials and of the influence exerted by their qualities over the methods employed by builders; but, independently of these particular qualities of the materials suitable for building, we repeat, the character of the people of these provinces presents great differences which influence the means adopted.

The transition is complete: of the Romanesque structure nothing remains; the principle of the equilibrium of forces has displaced the system of inert stability.

Every edifice at the end of the twelfth century is composed of a framework rendered solid by the combination of oblique resistances, or of vertical weights opposed to thrusts and of an envelope, a garment which clothes that framework.

Every edifice has its skeleton and its membranes; it is only a structure of stone, independent of the garment that covers it. This skeleton is rigid or flexible, according to the need and location; it

yields or resists; it seems to possess life for it obeys contrary forces, and its immovability is obtained only by means of the equilibrium of these forces, not passive but acting.

Already we have been able to appreciate the properties of this system in the description that we have given of the construction of the choir in the church of Notre Dame at Chalons-sur-Marne (Figs. 41, 42, 43); but how clumsy and, at the same time, labored, mean and complicated that structure appears, if we contrast it with the beautiful Burgundian constructions of the first half of the thirteenth century.

There all is clear, frank, easy to understand; and what wise hardihood! the hardihood of people, who are sure of not failing, because they have prepared for everything, have left nothing to chance and know the limits which good sense forbids them to pass.

We have reached that period of construction in the Middle Ages during which the nature of the materials used is to play an important part.

We cannot pass over in silence the remarks that ought to serve as an introduction to the methods of building used by the Gothic architects. They had built so great a number of public and private edifices during the twelfth century that we are not surprised to find among these builders a profound knowledge of the materials suitable for building, and of the resources furnished by their use.

The men who cannot acquire a very broad education, for want of instruction completed by the successive observations of several centuries, are obliged to make up for that elementary poverty by the keenness of their intelligence; and being unable to rely upon documents which do not exist, they must make these observations for themselves, collect them, classify them and form a theory from them. Experience alone guides them; it is not until later that rules are established and it must certainly be confessed that, however complete may be the theory, however numerous and good the rules, they never succeed in taking the place of the observation based on the experience of every day.

At the end of the twelfth century, the builders had quarried and cut so great a quantity of stone that they had attained to an exact knowledge of their properties and to the use of these materials, by reason of these properties, with a very rare intelligence. It was not then, as to-day, an easy matter to procure hewn stone; the means of preparing and transporting it were insufficient and it was necessary to obtain it on the spot; it was impossible to procure stones from distant regions: therefore it was by means of local resources that the architects had to raise their edifices and often these resources were feeble. People do not take sufficient account of these difficulties when they estimate the architecture of those times and they often blame the architects and consider as a puerile desire to raise constructions surprising for their lightness what was in reality only an extreme poverty of means. Building-stone was, in the twelfth and thirteenth centuries, comparatively what it is in our time, a material rare, and consequently dear; it was, therefore, necessary to manage and use it so as to make only the smallest amount possible enter into the construction. There is no need to refer to written documents to find out this truth; it is enough to axamine public and private edifices with some attention, and it is soon recognized that the builders not only never used one stone more than was needed but that also they never put into the work other kinds than those suitable to each place, scrupulously economizing on the most expensive stone, that is to say, upon those of very great hardness or of large size. Hand-work, on the contrary, being then rather inexpensive, the architects did not fail to make a lavish use of it. Moreover, it is quite in the order of things that when a material is costly in itself, one should seek to bring out its value by some extraordinary treatment. We recommend these observations to those persons who, not unreasonably, condemn the servile imitation of Gothic architecture. This is what one might say, but no one has yet thought of it: "If in the twelfth century, a cubic metre of stone was worth on an average two hundred francs,

and the day's work of a stone-cutter one franc, it was reasonable to use as little stone as possible in an edifice, and it was natural to bring out the value of that precious material by workmanship costing so little. But to-day when stone averages in value one hundred francs per cubic metre, while the daily wages of a stone-cutter represents six or seven francs, there is no longer the same reasons for so far sparing the stone at the expense of the solidity and for giving that substance, which costs so little, a workmanship which costs so dear."[1]

This argument would be more conclusive against the imitators of Gothic architecture than is, for example, the comparison of the nave of a Gothic church with the inverted hull of a ship; for this comparison is a eulogy rather than a criticism, as would be the comparison of the dome of the Pantheon with a bee-hive.

But let us leave these comparisons, which, as the proverb says, are not *reasons* and let us go on.

The builders in the Middle Ages were not acquainted with the sandstone saw, that long blade of wrought-iron, with the aid of which, by a horizontal movement back and forth, a workman can cut enormous blocks into slices as thin as occasion requires.

[1] Some one will perhaps ask how it can be that stone is so dear when handwork is so cheap, since stone acquires value only by the quarrying. To this we reply, in the first place, that the quarrying may be done with more or less skill and by means of more or less powerful machines; and that a very advanced state of industry always brings a diminution of price upon the raw material, because of the facility of preparation, of transportation and the use of improved machines.

A cubic metre of stone which will cost for transportation on a canal only five francs per forty kilometres, for example, will cost twenty or more francs if brought on wagons, supposing the distance traversed to be the same; while if the roads are bad, the difference will be very considerable. Now this is just what took place in the Middle Ages, without counting the tolls and the duties on quarrying, which were often enormous. Centralization is one of the surest means of obtaining raw materials at a low price. Formerly there was not an abbot or a noble in the land who did not exact the payment of duties of passage, and, these duties being arbitrary, there resulted a considerable increase upon the cost of quarrying. In proof of this, we see, for instance, monastic institutions going great distances to obtain stone because it comes from quarries belonging to them, and because they have only to follow the roads free of duties, while they do not take the materials which are nearer to them, but which must cross lands belonging to proprietors not vassals of the abbey.

There are still seventy departments in France where that very simple machine is not used and these are generally the places where they build the best, for the advantages of the sandstone saw may be disputed.

France abounds in ledges of limestone of great variety and excellence and easy to quarry. These ledges, as every one knows, are hard or soft, thin or thick, usually thin when they are hard and thick when they are soft. Now, there is always an advantage to be gained, in building, from respecting the order of nature; this has often been observed by the ancients and with still more scrupulous care by the Gothic builders. They have extracted and used the materials such as were furnished by the ledges of stone, even governing the members of the building by the height of these ledges. Never dividing a stone, as we do to-day in our work-yards, they set them up whole in their structures, that is to say, with the heart kept in the middle, their beds below and above, contenting themselves with *chiseling*[1] them off.

This method is excellent, for it preserves in the stone all its natural force, all its means of resistance.

If the early Gothic builders used soft stones for their points of supports (as they were often forced to do, in default of finding others), they took care to leave them a great height of course; for in this case soft stone is less liable to be crushed. As to hard stones and among others the thinnest, which are generally the strongest, they used these as ties, as lintels prolonged to connect distant piers with one another; and they composed the supports which were to carry a very heavy burden, either by piling the stones one upon another, if these supports were very thick, or by setting them upright, against their stratum, if the supports were very slender. With regard to these stones set against the stratum, we recognize all

[1] To chisel a stone is to take away from both of its beds the portions of lime which have preceded or followed the complete geological formation; in one word, to remove the parts liable to be decomposed by the action of the air or of dampness.

the delicacy of observation shown by the builders. They were not ignorant that stones set against the stratum are liable to split; wherefore, they chose them with particular care in shallow, very homogeneous and very compact ledges, in the building-stone at Paris, in the hard stones of Tonnerre[1] in Lower Burgundy and Champagne, in the small ledges of upper Burgundy, hard as sandstone and without strata.[2]

Experience had shown them that certain stones that were hard and fine in grain, like the Cliquart and the small hard ledge at Tonnerre, for instance, were composed of very thin courses of limestone set one upon another and united by a solid cement; that these stones through their very texture have, when set up against their strata, so to speak, an extraordinary strength; that they resist enormous pressure, and that when heavily loaded with a powerful weight they split less readily than if set on their natural bed, for what makes these stones split is the moisture which they secrete between their thin layers, and which causes the particles of marl to swell; now, if set flat, they are more apt to preserve that moisture than if set upright. In this latter case the water runs along their sides and does not penetrate the courses resting one upon another. As a proof of our statement we might cite a number of gutters, drip-stones and copings made of slabs of Lias or Cliquart, set on their natural bed, in very old buildings, and frequently found to be split; while the same materials in the same structure when set upright against the stratum are perfectly preserved and are injured only through accidents, like the oxidation of cramp-irons or gudgeons, or through some flaw.

We should not omit here one important fact in the constructions of the Middle Ages, that the beds are cut with the same perfection as the facings to be left in sight, and that the stones are always set

[1] These hard, shallow ledges of Tonnerre are no longer worked, although their qualities are excellent; they are called forest stones.

[2] Stones of Manse, Dornecy, Ravières, hard Coutarnoux, Anstrude, Thisy and Pouillenay.

in a thick bed of mortar and do not have the mortar put in with a trowel, or poured in, which is worse.

In conclusion, and to end this digression about the materials suitable for building, we will add that the builders of the first Gothic period have regulated their system of construction according to the materials at their disposal, and consequently the forms of their architecture.

A Burgundian architect in the twelfth century did not build at Dijon as at Tonnerre; for if we find in the same province the influence of the same school, in the execution of the masonry we remark considerable difference resulting from the nature of the stone employed. But as in each province there is one prevailing kind of material, the architects adopt a method of building in conformity with the nature of these materials. Burgundy, so rich in stone of a superior quality, furnishes us with the most evident proof of this fact.

CHAPTER VIII.

DEVELOPMENTS. (THIRTEENTH CENTURY.)

AT Dijon there exists a church of moderate size, under the name of Notre Dame; it was built about 1220, and it is a master-piece of reasoning, in which the science of the builder is hidden under an apparent simplicity. We shall begin by giving an idea of the structure of this edifice. The apse, without any aisle, opens upon the transept; it is flanked by two chapels or smaller apses facing the east like the chancel and opening into the transepts in the prolongation of the aisles of the nave.

The apse of Notre Dame at Dijon is composed, in the interior, only of a thick basement, not very high, carrying isolated piers connected in every direction, and having for the exterior enclosure only a sort of partition of stone pierced by windows. Naturally the piers are designed to support the vaults; as to the partitions, they support nothing, for they are only a means of enclosure. On the outside the building consists only of plain buttresses.

Figure 75 gives a perspective view of this apse; since it has no aisles, the buttresses support the vaults directly, without flying-buttresses.[1]

[1] We shall be permitted one remark upon this subject: while appreciating

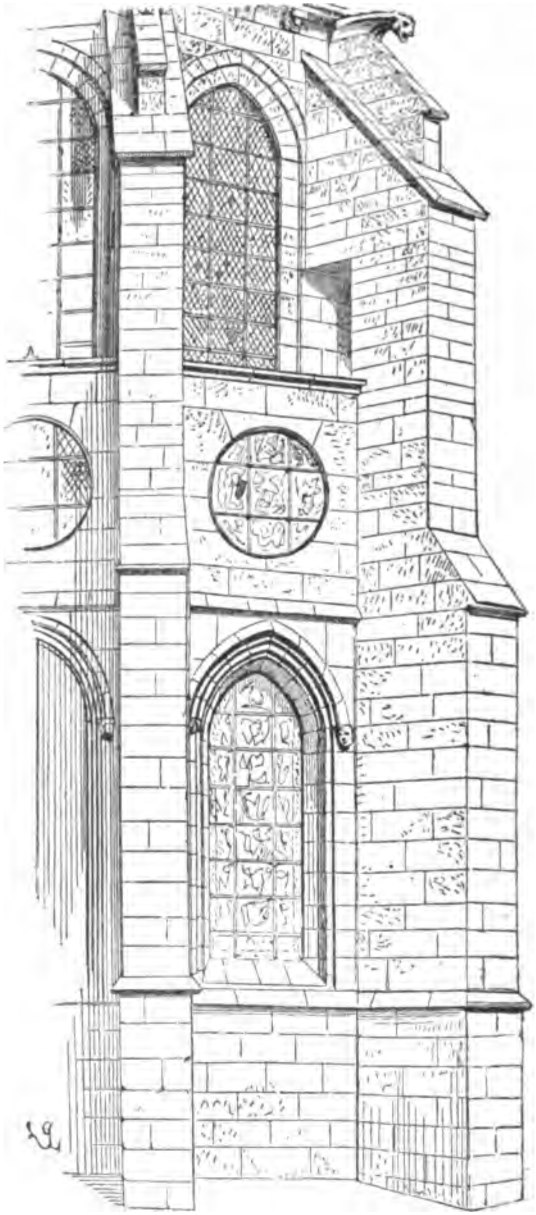


Fig. 75. Apse of Notre Dame, Dijon.

These buttresses are thick and solid and in them alone dwells the stability of the edifice. Nothing is simpler in appearance and in reality than this building. Thin walls pierced by windows close all the space left between the supports. An exterior passage is left at *A*, to facilitate repairs on the large glass windows. All the facings are well protected from the rain by sloping roofs without offsets, and by cornices or copings.

Clearly, this is only a solid envelope, a screen.

Let us now enter the Church of Notre Dame at Dijon. Just as the exterior is simple, solid, covered and screened, so the interior presents light and elegant arrangements. This edifice was built and still is situated in a populous quarter, surrounded by narrow streets, and the architect has felt it his duty to sacrifice everything to the interior effect. We recognize, moreover, that he must have been limited in expense, and must have avoided useless expenditure. He was chary of the materials and did not use one stone too many. The apse, accordingly, on the inside (Fig. 76) is composed of a thick

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more or less the merit of Gothic religious edifices, some critics (who are not architects, it is true) have claimed that of all the churches of the Middle Ages in France the most perfect, that which shows on the part of the architect the highest amount of talent, is the Sainte Chapelle at Paris, for that church keeps a perfect stability without the aid of flying-buttresses; and, starting from this point, the same critics, happy without doubt at having made this discovery, have added: "the flying-buttress, a permanent stone support, exposing the weakness of the builders, is thus only a barbarous over-growth, a useless toy, since even during the Middle Ages skilful artists knew how to do without it."

The argument is forcible; but the Sainte Chapelle has no aisles, and at the start, the architect was not obliged to cross that space and transmit the thrusts of the great vaults outwards, beyond those aisles. It is thus, nevertheless, that people nearly always talk of an art that they do not understand and the multitude applaud, for the professionals do not think it necessary to refute such arguments. They are wrong; for an error repeated a hundred times even by the most ignorant, but repeated with assurance, ends by being admitted among the most undeniable truths; and we still see printed to-day, in perfect good faith, on the subject of the arts, and especially upon Gothic architecture, arguments long since refuted by the criticism of facts, by history, by monuments and by demonstrations based on geometry.

All this labor of truth which seeks to assert itself passes unperceived before the eyes of certain critics, who probably boast that they forget nothing and learn nothing.

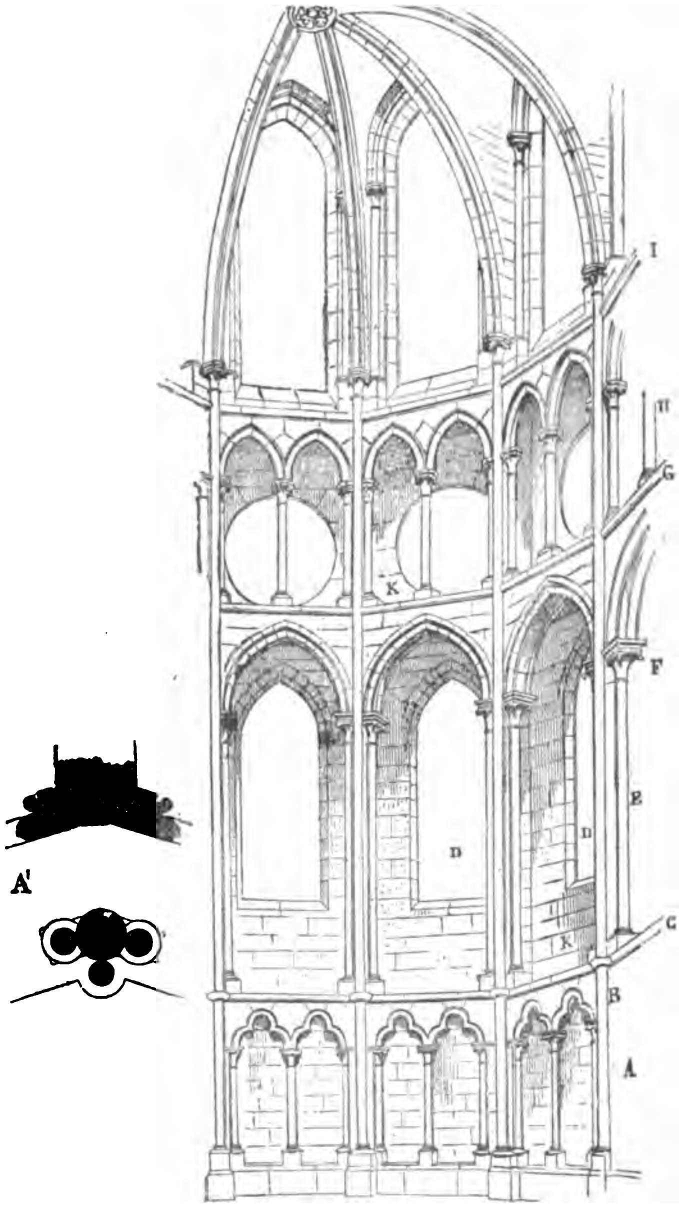

Fig. 76. Apse of Notre Dame, Dijon.

basement, *A*, built in courses and ornamented by an independent arcade inlaid in the wall. From this basement the pillars *B* start and rise to the extremities of the arches of the great vault. These pillars are set against the stratum from the base to the tablet *C*, which connects them in a moulding to the outer structure. Over this basement is a passage or gallery, designed to facilitate access to the glass windows *D*, and to decorate the church, if necessary, on holy-days. The piers *E* are detached; they consist of four columns set against the cleavage from base to capitals, a large one (37 centimetres in diameter), and three slender ones (from 12 to 15 centimetres in diameter).

In *A′* we give the section of these piers. The large column and the two at its side are each in one piece as far as *F*, the course of the capitals, while the pillar starting from the ground is in one piece as far as the tablet *G*.

This tablet *G* forms a ceiling over the lower gallery, and connects the large arcade with the outer walls.

At the height of the gallery on the third row (the triforium) there is the same arrangement of the piers and the same section *A′*, only an intermediate pillar, *H*, bearing an arcade composed itself of large, thin pieces of stone, like slabs (flags) set upright.

Above the triforium, a second flagging, *I*, serves as a ceiling for this triforium, and attaches the arcade to the outer building; next comes the starting-point of the arches of the large vault, supported by the exterior buttresses.

The high windows then open above the archway of the triforium and are no longer in a recess, as below, in order to give all the light possible and to leave on the outside the passage of which we have spoken before.

Thus the thrust of the arches is transmitted obliquely to these exterior buttresses, which are built in courses, and the inner piers are only rigid points of support, incompressible because consisting of large stones set against the cleavage, but presenting, because of their small impost, only a frame capable of bending, at need, to one

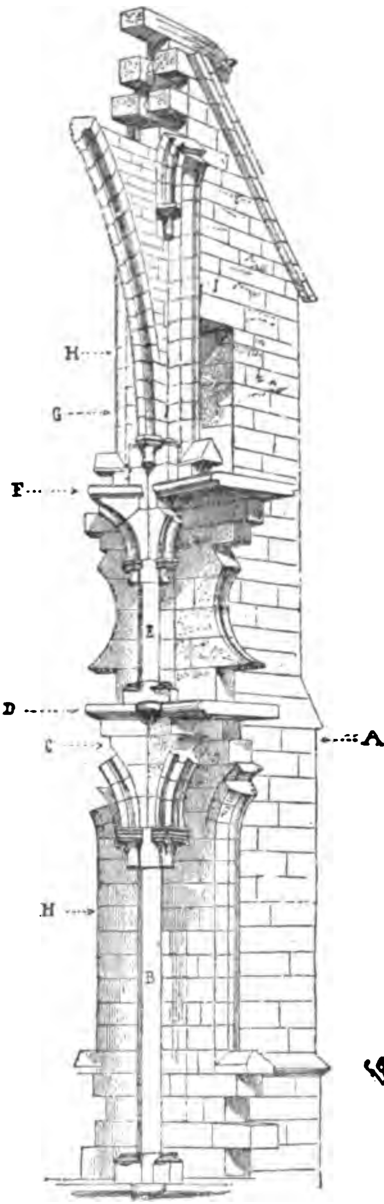

Fig. 77. Construction of the Apse, Notre Dame, Dijon.

side or the other, without or within, without danger, should any settling occur.

As to the walls *K*, they are, as we have seen, only partitions 20 centimetres thick at the utmost. Now let us take away from this structure everything not essential to it, let us take its skeleton and this is what we shall find (Fig. 77): *A*, a buttress, built up and a passive mass; *B*, a column, slender but rigid and resisting like cast-iron, thanks to the quality of limestone used; *C*, courses at the height of the arches and, consequently, flexible at need; *D*, the connection between interior and exterior; *E*, a second column, but shorter than the one below, for, since it is higher up, any movement taking place there would have more effect; *F*, a second course joining interior and exterior; *G*, the skew-backs of the arches; *H*, simple walls that support nothing and serve only to enclose the

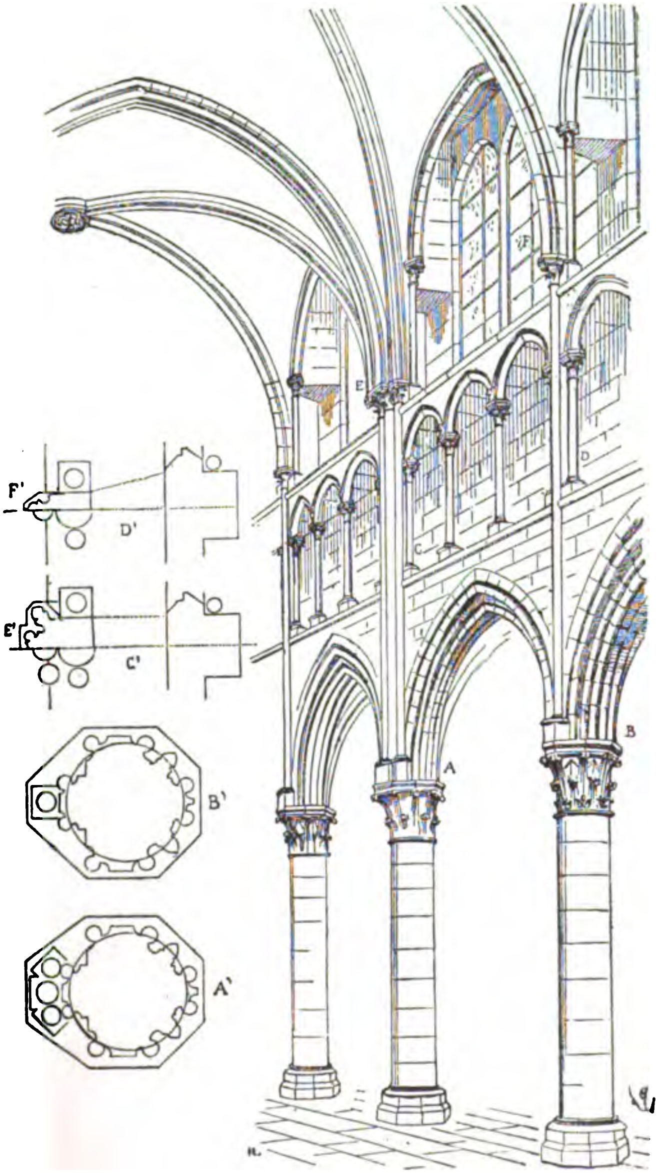

Fig. 78. The Nave of Notre Dame, Dijon.

building; *I*, the abutment placed only at the point where the thrust of the arch acts.

There is nothing too much, but everything that is necessary, for this construction has stood for more than six centuries, and does not yet seem near its fall.

It is not necessary to recall here what we have said about the function of the monolithic pillars that accompany the columns *B* and *E*, and which we have supposed removed in Figure 77. They are only accessory supports which give firmness and stability to the principal columns, without being absolutely indispensable.

The weight of the vaults rests far more upon the buttresses, because of the action of the thrust, than upon the cylinders *B* and *E* (see Fig. 33).

As the interior clusters of pillars carry only a very slight weight, there was no need of giving them great resistance. But if we had an aisle, if the buttresses, instead of being immediately opposed to the action of the vaults, were removed by the whole width of this aisle, then the vertical piers should have a larger impost, for they really would carry the weight of the vaults.

The nave of this same Church of Notre Dame at Dijon is vaulted according to the early Gothic method.

The diagonal arches are on a square plan and are cut by a transverse arch.

The lower piers are cylindrical, built in drums and of equal diameter. Still, each pair of capitals differs somewhat, for they carry alternately either a transverse and two diagonal arches or one transverse arch only. We give (Fig. 78) the view of an inner division of the nave of Notre Dame at Dijon.

At *A′* we have drawn the section of the impost *A*, in *B′* the section of the impost *B*, with the horizontal projection of the abaci of the capitals. These capitals jut out farther on the side of the nave, to receive the pillars which rise to the beginning of the vaults, always in accordance with the principle which consists in moving back the vertical supports so as to draw off a part of the thrusts (see Fig. 34).

In C' we give the horizontal section of the piers C, and in D' that of the piers D, at the level of the triforium, at E' the horizontal section of the skew-backs E, and at F' that of the skew-backs F, on a level with the abaci receiving the great vaults.

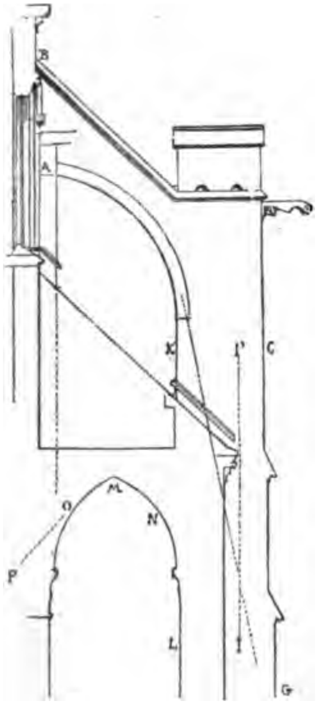

Fig. 79.

This general sketch having been given, let us examine with care the structure of this nave.

We have already said that the architect of Notre Dame at Dijon had at his disposal a limited area crowded in between narrow streets; so he could not give to the buttresses of the nave supporting the whole system a great projection beyond the perimeter of the aisles.

If he had followed the methods adopted in his time, if he had remained submissive to routine, or, to be more accurate, to the rules already established by experience, he would have designed the flying-buttresses of the nave as indicated in Figure 79.

The thrust of the great vault acting from A to B, he would have placed the last voussoir of the arch at A and its coping at B and he would have moved the front of the buttress from C in such a way that the oblique line of the thrusts should not pass the point G. But he cannot go beyond the point I: since the width reserved for the public road does not allow it; and, on the other hand, on the interior he cannot pass the point K, which is on the vertical of the engaged pier L, without

causing a false bearing and of breaking the transverse arch M, whose curve it is important to keep; for if a too considerable weight acts upon the haunches of that arch at N, that arch will push the detached pier on the interior in the direction $O\ P$. Hence the architect must fix the pier of his flying-buttress in the space included between K and I'. But we know that this pier must be passive, immovable, for it is the true point of support for the whole system; and it can evidently acquire that immovability (its narrow base being taken into consideration) only by a particular arrangement, a supplementary vertical resistance. Accordingly, the constructor solves the problem as follows: he builds the pier between the two points desired (Fig. 79*b*); he loads heavily the summit of the flying-buttress at A; he slopes the coping $B\ C$ so as to make it tangent to the extrados of the arch; then he brings the rear surface of the pinnacle D, over to the point E out of the vertical of the wall F, so that the space $P\ F$ may be a little less than a third of the space $F\ G$. Thus the thrust of the great vault is strongly opposed, in the first place, by the weight A and is neutralized by that pressure: so that now only the flying-buttress itself acts upon the pier K, so far as it is loaded at A. Accordingly, if that arch were to be put out of shape, it would be in accordance with the drawing R; it would break at S and the pier K would bend.

But the architect moves back his pinnacle and loads the pier outside of its perpendicular as far as the point E, that is to say, as far as the point where the rupture of the flying-buttress might take place; he thus checks that rupture, for under its load the point S' of the flying-buttress cannot be displaced; but the pinnacle D only presses against the arch, while it does not weight it, since the space $C\ O$ is greater than the space $O\ P$; hence the weight of the pinnacle, which is a well-built, homogeneous construction of large stones, rests on $O\ C$, the centre of gravity of the pinnacle being between O and C; consequently if the arch were torn down, this pinnacle would remain upright; thus it loads the pier K, with a greater

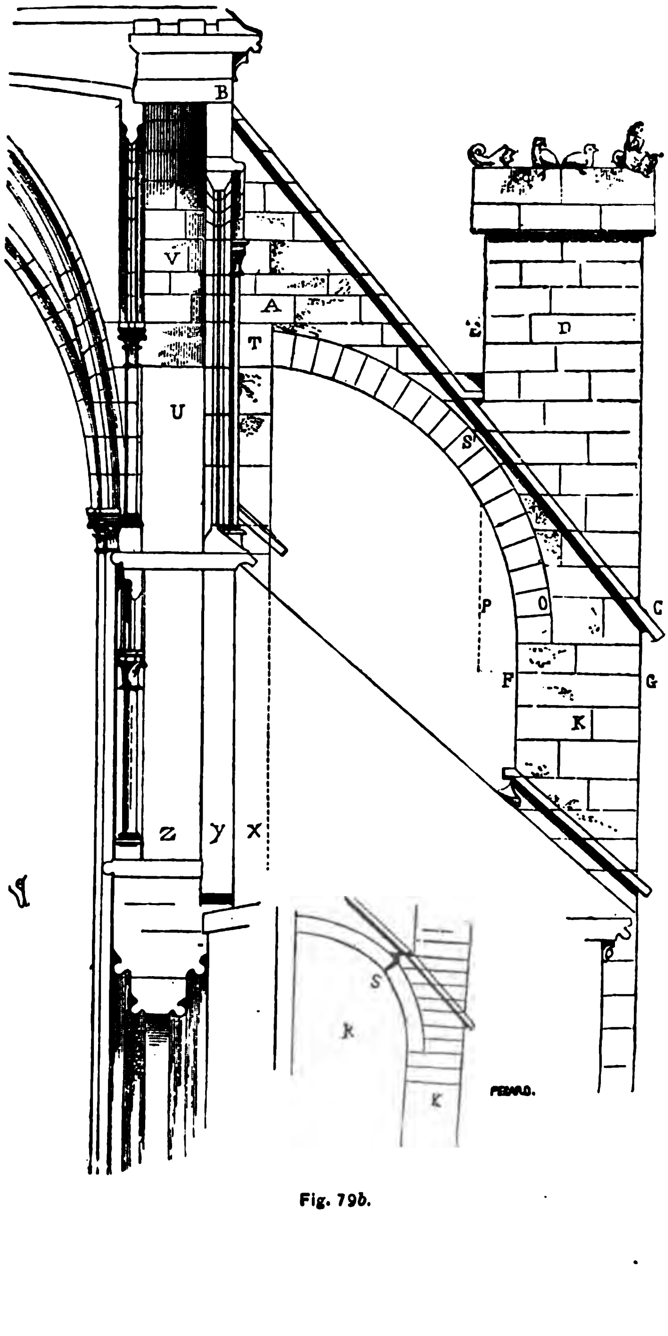

Fig. 79*b*.

weight than that of a pinnacle having only *F G* in breadth; and hence assures in this way the stability of the pier *F G*, too feeble by itself to resist the thrust without the addition of this weight, while, at the same time, he compresses the haunches of the flying-buttress at the point where that arch would tend to break if thrust out of place.

Fact is more conclusive than all logical deductions; the construction of the nave of Notre Dame at Dijon, in spite of slightness of its exterior supports, has not undergone the least deformation. Let us not lose sight of the interior; let us notice that the vaults do not push directly upon the tops of the flying-buttresses and that between the tops of these arches and the skew-back of the vault there exists, above the triforium *U*, an interior support *V* just at the height of that thrust, neutralizing its action in a singular manner. Let us study the details: the block of stone *T*, against which the last voussoir of the flying-buttress rests, is no other than the lintel carrying the support of which we were just speaking and at the same height as this lintel are fixed the two capitals which carry the wall-arches of the vault (see Fig. 78). This lintel is set just on the level of the action of the thrust from the great vault.

Let us analyze this construction piece by piece (Fig. 80).

We see at *A* the column, the principal support of the triforium at the height of the piers carrying the extremities of one transverse and two diagonal arches, a support flanked by the two lesser columns *B*.

At *C* are the large pillars set against the stratum upon the abacus of the large capital on the ground-floor and passing in front of the group *B A B* in order to arrive under the course *M* of the capitals of the arches of the great vault; a course consisting of a single stone.

At *D* is the capital of the triforium.

At *E* is the skew-back of the arcade of the triforium, also consisting of one stone.

At *F* are the two blocks closing the arcade.

At *G* is the course forming the ceiling of the triforium and connecting the arcade and the course of the capitals *M* to the exterior

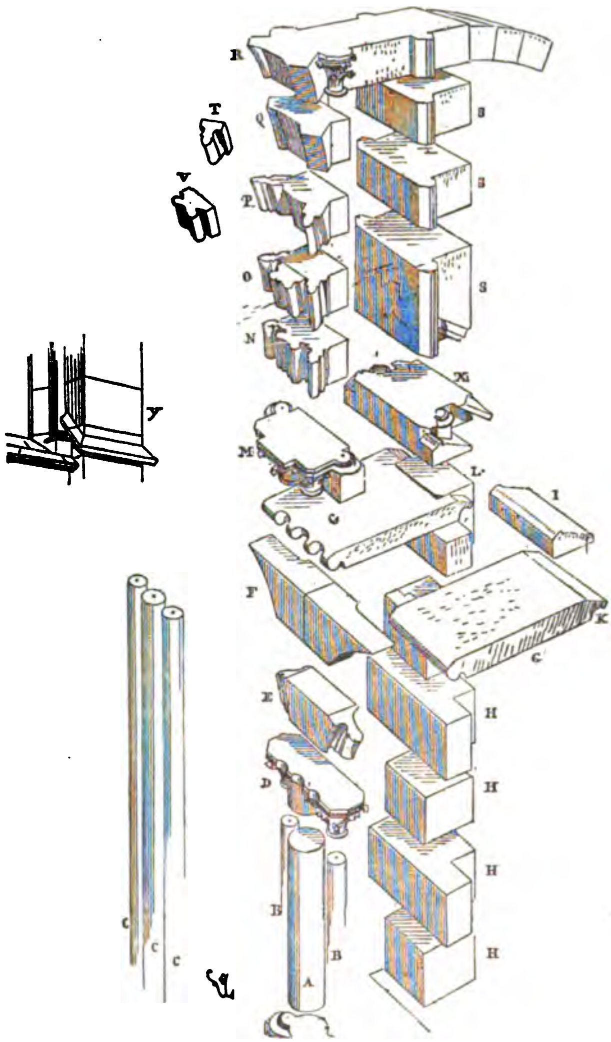

Fig. 80.

support, under the roof, a support whose courses are drawn at *H*.

At *G'* is one of the slabs, placed next to that at *G* and connecting the rest of the arcade to the partition built under the upper windows, of which *I* is the sill.

These slabs *G'* carry the fillet *K*, projecting over the roof of the aisle.

At *L* is the first section of the exterior buttress seen above the roof.

At *M* is the course of the capitals of the great vaults, carrying the bases of the two pillars, set against the stratum, which sustain the wall-arches.

At *N* is the skew-back of the great vaults, whose upper bed is horizontal and which carries the extremities of the two diagonal and the transverse arches.

At *O* is the second skew-back carrying the two diagonal arches and the transverse arch, the upper bed of the latter being now normal to the curve, while the beds of the two diagonal arches are still horizontal.

At *P* is the third skew-back, no longer carrying the transverse arch, which is henceforth independent, but still carrying the two diagonal arches whose beds are horizontal.

At *Q* is the fourth skew-back, carrying nothing but the shoulder-piece behind the diagonal arches, for laying the first filling-stones.

At *R* is the lintel, of which we were just speaking and which connects the skew-backs with the pier whose courses are at *S;* this lintel carries the shoulder-pieces behind the diagonal arches, for it is important to give firm support to these now independent diagonal arches whose voussoirs are represented at *T*, while one of the voussoirs of the transverse arch is given at *V*.

At *X* is the course of the exterior buttress carrying the ledges of the windows, the bases of the exterior pillars of these windows and the fillet passing above the list (or fillet-ridge) of the roof, as the perspective detail *Y* indicates.

The terminus of the voussoirs of the flying-buttresses then rest

against the lintel *R* and, beginning with the lintel, the interval between the pier and the vault is filled (see the interior view, Fig. 78).

If we examine the section (Fig. 79*b*), we see that the buttress *X*, the wall of the triforium *Y*, the passage *Z* and the inner pier present a considerable thickness; for the passage is quite wide and the wall and buttress together measure about 60 centimetres and the group of columns forming the inner pier about 50 centimetres.

Now, all this must rest upon a single capital, crowning a cylindrical column.

There will be evidently an imperfect balance and if the buttress *X* bears upon the haunches of the transverse arch of the aisle, the pressure that it will exert will push the column inward and make it lose its upright position and, the upright position once lost, the whole equilibrium of the building is destroyed.

The builder has at first given to the capital (Fig. 81) the form *A*; that is, he has moved the axis of the column into the vertical plane passing through the middle of the archivolt *B*.

Upon this capital he has placed the two skew-back stones *C* and *D*, with their beds horizontal: the first skew-back *C*, carrying the bases of the pillars set against the stratum and rising to the beginning of the great vaults, while the third skew-back *E* has its sections normal to the curves of the transverse arch, the diagonal arches and archivolts, for, on starting from this skew-back the arches detach themselves from one another.

Having set free the arches, which henceforth are laid in independent voussoirs, the builder has erected a pier, having projections to the right and left, *F*, *G*, *H*, *I*, *K*, in corbels, up to the vertical of the buttress *L*; and in the course *I*, he has taken care to reserve two skew-backs *M*, to receive the arches sustaining the wall of the triforium *N*.

The interior pier *O*, composed, as we have said before, of a cluster of pillars, set against the stratum, rests upon the inner part of that

pier. It is understood that its courses *F*, *G*, *H*, *I*, *K*, are each in one piece and strong.

The heaviest weight and the most stubborn resistance are those of the pier *O*, since it carries vertically the buttressed vaults; for the buttress *L* carries almost nothing, since the summit of the flying-buttress does not weigh upon it (see Fig. 79*b*), and it merely keeps the structure in equilibrium. Accordingly the stones *K*, *I*, *H*, being weighted at the ends *K' I' H'*, cannot sway; hence the buttress is held firm.

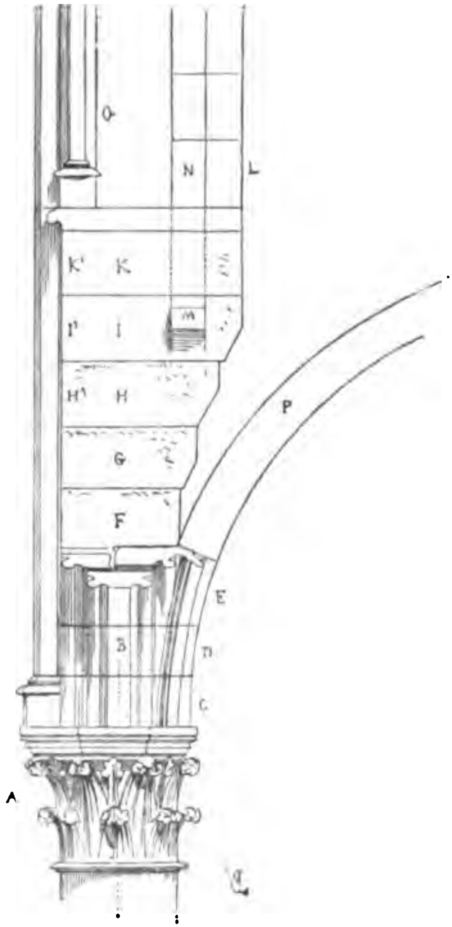

Fig. 81.

As to the thrust of the transverse arch *P*, and that of the diagonal arches of the aisle, it is wholly neutralized by the weight which presses downwards in the vertical of the pier *O*. It is now understood how essential it is that the pier *O* should be composed of large stones set upon end and not of courses,

for this pier supports a twofold pressure: that from above down-

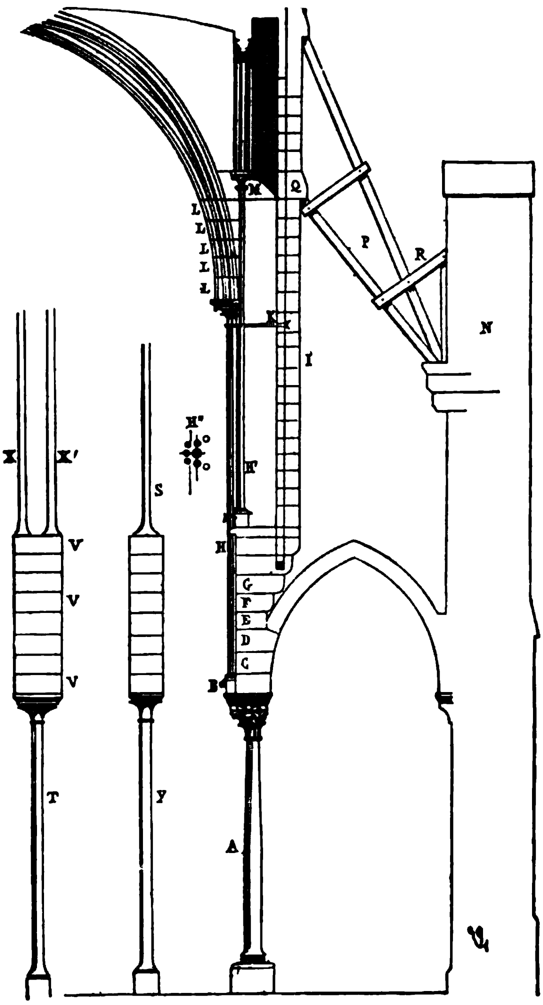

Fig. 82c. Fig. 82b. Fig. 82.

ward, caused by the weight of the vaults and that from below

upward, in consequence of the tendency to tip, produced by the buttress *L* upon the ends of the stones *K*, *I*.

If, then, these piers *O* were built in courses, it might happen that the mortar joints, if strongly compressed, by that twofold action, would diminish in thickness; now the least settling in height of the piers *O* would result in deranging the equilibrium of the entire system.

On the contrary, the leverage produced by the courses *I* and *K*, under the pier *O* has the result (those pillars being perfectly rigid and incompressible) of sustaining very firmly the starting point of the great vaults.

We shall the better understand this system of building by supposing, for example, that in order to execute it, cast-iron, stone and wood have been employed (Fig. 82.)

Let the column *A* and its capital of cast-iron be set upon a pedestal of stone and let them support the stone skew-back *B*.

The builder gives a broader projection to the capital toward the interior of the nave than on the side of the aisle. Upon this capital he raises the courses *B*, *C*, *D*, *E*, *F*, *G*, etc., in the form of corbels. He sets three iron columns *H* along the inner wall and augments them by three other columns *H'* (see section *H''*); these columns *H H'* are attached to the buttress *I* by rings and a cramp-iron *K*, in order to make the buttress fast to the pier and to hinder the rounding outward of either.

The buttress *I* is built of courses of stone. Upon the columns *H H'*, the architect places the skew-backs *L* of the great vault; the two side columns *O O* continue alone up to the lintel *M* which buttresses the arches of the great vaults.

On the outside he raises a pier *N* of stone, in order to be able to keep the interior structure in the vertical, by means of the prop *P*, strengthened to prevent its displacement, by the cross-pieces *R*.

There is no inconvenience, on the contrary, in case the buttress *I*, built in courses, should be compressed, or should settle; for the

lower the point Q falls, the more rigid will be the prop P against the back of the lintel M. Nevertheless, this buttress I is needed to keep the back of the lintel M in a horizontal plane, but most of all to give stability to the column A. In fact, one need not be very well versed in the knowledge of the laws of equilibrium to know that if, between a column Y and a column S, both slender (Fig. 82*b*) we place several horizontal courses, it will be impossible, however well loaded the column S may be and however well propped may be the courses, in one sense, to keep these two columns in a vertical plane, parallel to the plane of the props; while, placing on the column T (Fig. 82*c*) horizontal courses V propped in one direction and upon these courses two pillars X X' passing through a vertical plane perpendicular to the plane of the props (always supposing the two pillars $X X'$ to be loaded) we shall be able to keep the columns $X X'$ and T in planes parallel to the props. In this consists the entire system of construction of Gothic naves set upon columns.

That is the explanation of the galleries set one above another in Burgundian architecture, a sort of hollow buttress whose inner wall is rigid and its outer wall compressible, thus giving great strength of resistance and of impost to the springings of the high vaults, avoiding enormous abutments to support the flying-buttresses and destroying, by its equilibrium and its pressure upon two distant points, the effect of the thrusts from the vaults of the aisles.

In truth, all this may well appear complicated, subtle and labored; but it will certainly be conceded us that it is ingenious, very skilful and scientific, and that the authors of this system have made no confusion of Grecian art with the art of the North; of the Roman with the Oriental; that they have not put caprice in the place of reason and that there is in these constructions more than the appearance of a logical system.

We freely admit that one may prefer a Grecian, Roman or even a Romanesque construction to that of the church of Notre Dame at

Dijon; but we shall certainly be permitted to believe that there is much to be gained here, by us architects of the nineteenth century, called upon to raise very complicated edifices, to strive with matter, while possessing materials very different in nature, properties and mode of use; forced to arrange our constructions in view of new needs, of widely varying purposes, very different from those of the ancients; . . . that there is more to be gained here, we repeat, than from the primitive and simple structure of the Temple of Minerva at Athens, or even than from the solid immovable structure of the Pantheon at Rome.

It is unfortunate that we could not always build like the ancients and perpetually observe the very simple and very beautiful rules of the Greek or Roman builders; but we cannot reasonably build a rail-road-station, a market, a hall for our assemblies, a bazaar or an exchange, in accordance with the workings of the Grecian or even of the Roman system, while the supple principles already applied by the architects of the Middle Ages, after careful study, place us upon the modern path, that of incessant progress. This study permits us every innovation, the use of all kinds of material without abandoning the principles established by these architects, since these principles consist essentially in submitting everything, materials, form, general arrangements and details to the reason; in reaching the utmost limit of possibility, in substituting the resources of industry for inert force and the search after the unknown for tradition.

It is certain that if the Gothic builders had had at their disposal large pieces of cast-iron, they would not have failed to use that substance in their buildings and I would not guarantee that they would not sooner have arrived at results more judicious and more logical than those obtained in our time, for they would have taken that substance frankly for what it is, profiting by all the advantages that it presents and without trying to give it other forms than those appropriate to it. Their system of building would have allowed them to use at the same time cast-iron and stone, a thing that no one has

dared to attempt, during our epoch; so much power has routine over our builders, who never cease talking about progress, like the singers in the opera, who cry "Let us start!" for a quarter of an hour without moving from the stage.

We are not aware that any one has attempted, in France, up to the present day, unless it is in the building of houses in several large cities, to place considerable masses of masonry, vaults of brick or even of stone, good structures well planned and executed, upon detached supports of cast-iron.

It is because *classic* teaching can hardly permit these attempts, which the architects of the Middle Ages would certainly not have failed to make and probably with entire success.

We certainly cannot reproach the Gothic builders with stopping halfway; we shall see with what ardor they throw themselves into the more and more rigorous application of the principles which they have laid down, and how they succeed, in a few years, in carrying these principles to their limit, in using materials with an exact knowledge of their qualities and in mastering the most intricate problems of descriptive geometry.

The Church of Notre Dame at Dijon is a small edifice and one might suppose that the Burgundian architects of the first half of the thirteenth century did not permit themselves similar hardihood in monuments with broad extent of surface and very high. It is the contrary which takes place; it seems that working on a large scale these builders gather more assurance and develop with still more boldness their means of execution.

The choir of the Cathedral of St. Stephen at Auxerre was rebuilt from 1215 to 1230, over a Romanesque crypt (see *Crypte*), which led to the adoption of certain arrangements, unusual in the large churches of that period. Thus the chancel is surrounded by a simple aisle with single square apsidal chapel.

As to its construction, it presents a perfect analogy, in the lower part, to the Church of Notre Dame at Dijon. At Auxerre, neverthe-

less, the structure is lighter yet and certain difficulties resulting from the Romanesque arrangement of the plan, which they did not wish to change, have been solved in the most ingenious manner.

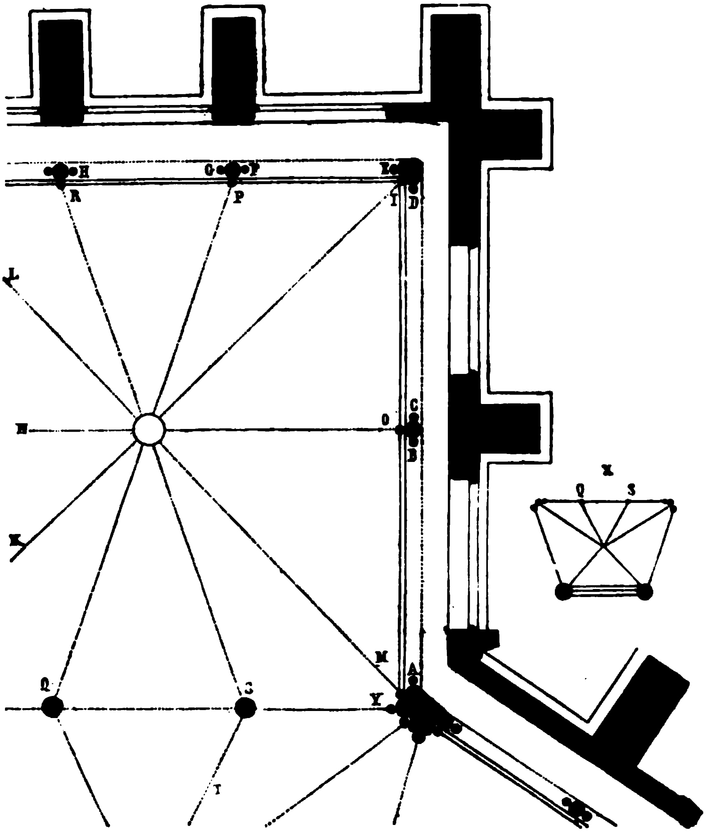

Fig. 83. Chapel of the Holy Virgin, Cathedral of St. Stephen, Auxerre.

We give (Fig. 83) half of the plan of the apsidal chapel, sacred to the Holy Virgin. This plan is taken at the height of the gallery of the ground-floor, resting, as in Notre Dame at Dijon, upon an

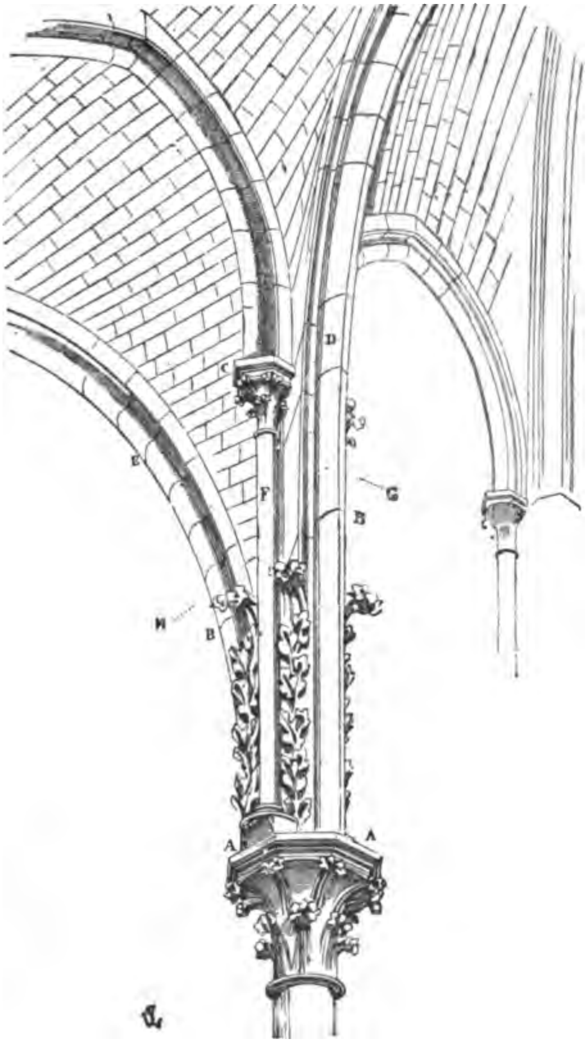

Fig. 84. From the Chapel of the Holy Virgin, Cathedral of St. Stephen, Auxerre.

arcade. At *X*, we have represented, on a smaller scale, the horizontal projection of the vault of the aisle in front of that chapel.

According to the Burgundian method the wall-arches are detached from the wall, they rest upon the pillars *A B*, *C D*, *E F*, *G H*, etc., set against the stratum.

The central pillars, likewise set against the stratum, sustain the force of the pressure and the vault consists of two diagonal arches *I K* and *L M*, one transverse arch *N O* and the intermediate arches *P Q* and *R S*.

These two intermediate arches fall, at the right of the aisle, upon two detached columns *Q* and *S*, set against the stratum, each in one piece and having twenty-four centimetres of diameter to six metres sixty centimetres of height from base to capital. The difficulty was to neutralize so exactly the different thrusts, acting on these columns *Q S*, that they could not leave the vertical.

It was a problem to be solved, similar to that which the builder of the chapels of Notre Dame at Chalons-sur-Marne had set before himself, but upon a much larger scale and with points of support incomparably more slender.

Let us take our stand for an instant in the aisle and look at the summit of the column *S*, whose diameter, as we have already said, is only twenty-four centimetres. Upon this column is placed a capital, whose abacus is octagonal and broad enough to receive the beginning of the two arches *S T* and *S R* and in addition two small columns carrying the transverse arches *S Q* and *S Y*.

A tall skew-back, whose lower bed is at *A* (Fig. 84) and its upper bed at *B*, is reinforced in the angles obtained between the arches and the pillars by sheaves of foliage. Up to the level of the abacus of the capital *C*, the arch *D* of the aisle rises and curves already, by means of two other skew-backs with horizontal beds, while the arch *E* (the intermediate arch of the chapel) of a greater diameter is farther out of the vertical and is composed, after leaving the bed *B*, of independent voussoirs.

The pillars, *F*, of the transverse arches at the entrance of the chapel are monoliths and balance these skew-backs, keep them rigid, and rest firmly upon the two faces of the abacus. Figure 85 gives the section of the beginning of the vaults at the level *G H*. This

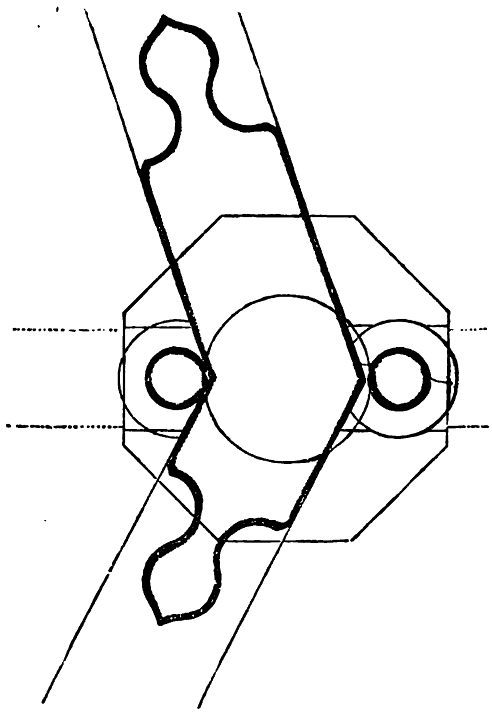

Fig. 85.

construction is bold, one cannot deny, but it is perfectly solid, as during six centuries and more it has undergone no alteration.

We see in this one of the most ingenious applications of the Gothic system of vaults, the unequivocal proof of the freedom of the builders, of their sureness of execution and their perfect familiarity with the resistance of materials.

These pillars are made from the hard stone of Tonnerre, as also the skew-backs.

As to the effect produced by this chapel and its entrance, it is surprising, but does not inspire that anxiety which every too-daring attempt causes.

The arches buttress one another so well not only in reality but also in appearance, that the eye is satisfied.

Even to that fourfold sheaf of foliage surmounting the capital and giving body to the lowest skew-backs, everything concurs in reassuring the observer.

Some one may object to these two columns at the entrance.

Why is not the architect content with throwing a transverse arch from one pier at the angle of the chapel to the other?

To this there is but one reply; let us turn back to Figures 41, 42 and 44, and the explanation is given; it is necessary, because of the radiating form of the aisle, to obtain upon the outer boundary a greater number of points of support than upon the inner boundary, in order to have the transverse arches almost equal at the base and exactly equal under the key, to close the triangles of the vaults at the same level.

If the vaults of the chapel of the Holy Virgin and of the aisle of the Cathedral of Auxerre are arranged like the majority of Burgundian vaults of the thirteenth century, that is, if their wall-arches are distinct from the walls and if a flagging supporting a water-channel unites these wall-arches to the tops of the walls, the architect of the choir has probably not believed that this process of construction was solid enough to finish off the great vaults of the principal nave.

He has had to fear the equilibrium of this system in a very vast edifice and he has chosen a middle course between the system of Champagne and that of Burgundy.

The system of Champagne certainly consists in detaching the wall-arch from the wall, but also in fastening between this wall-arch and the wall a cradle-vault over the extrados of the aforesaid wall-arch.

Let us examine then in what the system of Champagne consists. We see it reaching its zenith in a little edifice of the Marne, the Church of Rieux, near Montmirail.

We first give (Fig 86) half of the plan of the apse of this pretty church. It is seen that this plan strongly resembles that of the apse

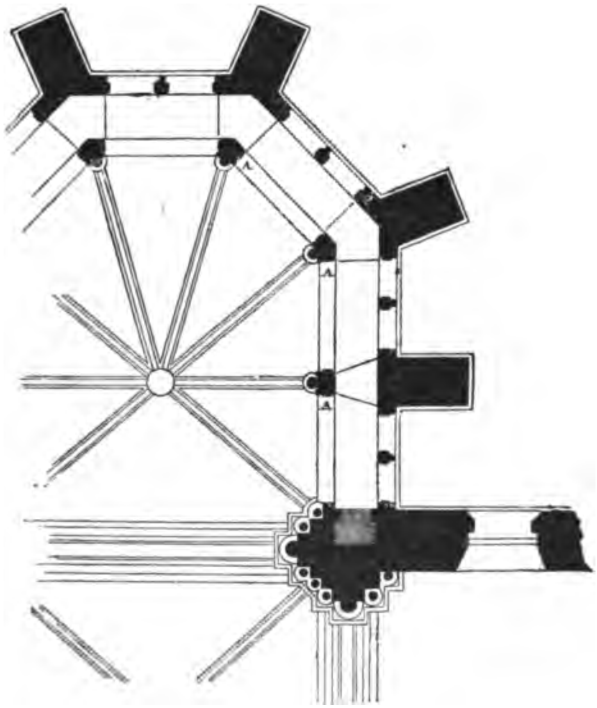

Fig. 86. Apse of the Church at Rieux on the Marne.

of Notre Dame at Dijon. But we are in Champagne, in a territory where materials of resistance and great size are rare; accordingly the small piers *A* are no longer composed of columns set against the stratum; they are groups of attached columns presenting a large

enough section to be built in courses. Furthermore, these piers, instead of being tall, are short.

Let us now examine the apse at Rieux in the interior (Fig. 87); we see at *B* the cradle-vaults concentric to the wall-arches, extending towards them, circumscribing the windows and supporting the beams of the roof and outer cornice.[1]

Accordingly, here are two adjoining provinces, Burgundy and Champagne, both of which start from the same principle of construction. But in the first of these provinces, the materials adapted to masonry are abundant, hard and easy to extract in large pieces and the constructions partake of the qualities peculiar to Burgundian limestone; in the second, on the contrary, are found only beds of chalk or marl, of very little solidity and impossible to extract from the quarries except in small pieces; hence the architects regulate their mode of construction by the nature of the stone of their province.

The Church of Rieux dates from the first years of the thirteenth century; its sculpture belongs almost to the twelfth.

Champagne is in advance of Burgundy and even of Ile-de-France, when it is a question of developing the principles of Gothic construction.

Already, the windows of the apse at Rieux are provided with mullions set against the stratum, while in Ile-de-France they are not seen until twenty years later and in Burgundy only about 1260.

The method indicated in Figure 87 for the construction of the vaults and the piers that support them is applied in the apsidal chapel of the Church of Sainte Remy of Rheims, earlier by twenty years, at least, than the apsis of the Church of Rieux; it is developed in the Cathedral of Rheims, in all the vaults of the chapels and of the great nave [see "*Cathédrale,*" Fig. 14, "*Chapelle,*" Fig. 36].

Let us now return to the Cathedral of Auxerre and let us examine

[1] M. Millet has had the goodness to sketch for us this charming little edifice, so very little known, the best type perhaps, of the architecture of Champagne at the beginning of the thirteenth century.

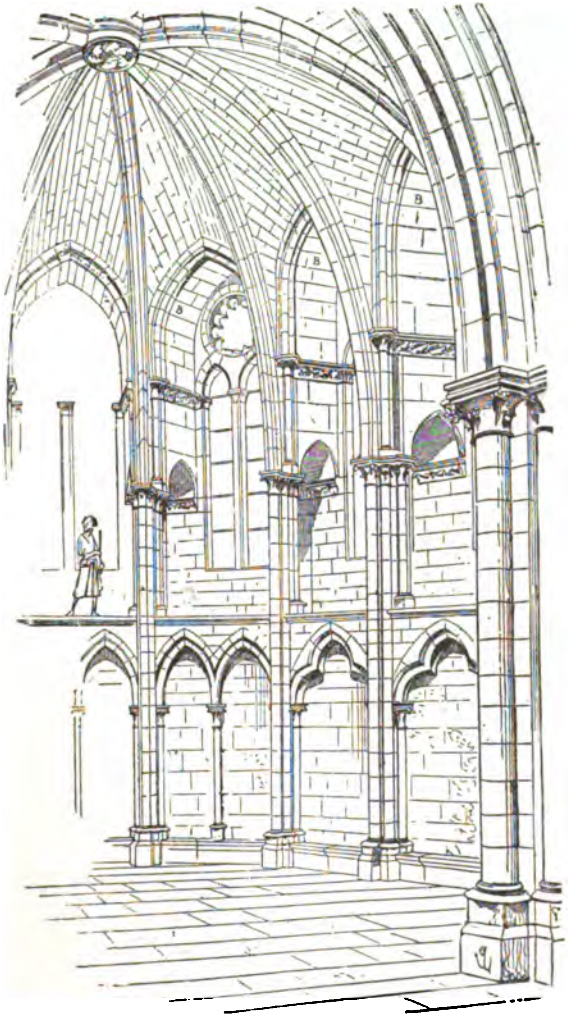

Fig. 87. Apse of the Church at Rieux on the Marne.

the advantage that its architect has been able to derive from the two methods, of Burgundy and of Champagne.

We give (Fig. 88) a view in the interior of the upper part of the

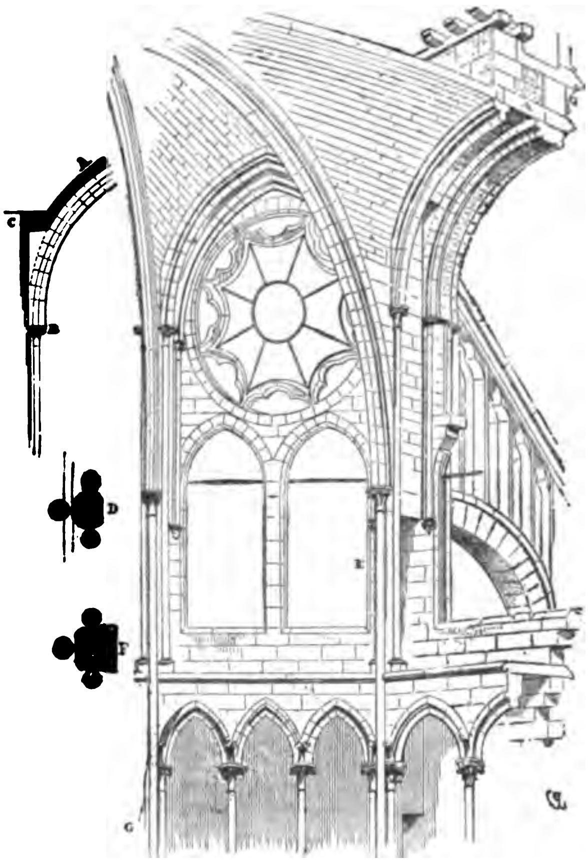

Fig. 88. Choir of the Cathedral, Auxerre.

choir; we have supposed one of the great windows removed, to show how the flying-buttresses sustain the vault and how the interior

buttress is cut through at the height of the triforium and of the gallery above.

At *A* we perceive the cradle-arch fixed between the wall-arches and the archivolts of the windows; but, by a concession to the Burgundian system, this cradle-vault does not start as, in Champagne, from the capitals *B*, but a little higher up from a lintel *C*, placed upon the sides of the interior buttress.

This cradle-vault is here fixed upon the extrados of the wall-arch, but it is independent; while, in the system of Champagne, the cradle-vault and the wall-arch are one, or, rather, the cradle-vault is simply a very broad wall-arch. The tracery of the windows is built in courses and not composed of columns and of bars set against the stratum. We give at *D* the horizontal section of the high pier at the level *E;* and at *F*, the section of the pier at the level *G*, of the triforium.

Following the Burgundian plan, these piers are set against the stratum for their entire height.

The cornice and water-channel above do not rest then upon a flagging, as in the aisles and in the chapel of the Virgin, of the same edifice, but upon the arches *A*.

The trusses of the roof are laid upon the wall-arches.

The gutter above throws its waters upon the copings of the open-work that surmounts, weights and consolidates the flying-buttresses. These copings have enough resistance and thickness and are firmly enough sustained by the open-work, whose upright positions are close together, so as to form an actual prop of stone opposing its rigidity to the thrust of the vault.

Figure 89 gives the exterior view of one of these flying-buttresses, very well built and well protected by the projections of the copings.

Let us leave, for a moment, the provinces of Champagne and Burgundy to examine how, during the same time (that is, from 1200 to 1250), the Gothic methods of construction had progressed in the French provinces Ile-de-France, Picardy and Beauvoisis.

One of the qualities peculiar to Gothic architecture (and, perhaps, its most striking one) is that one cannot study its form, appearance or decoration independently of its structure.[1]

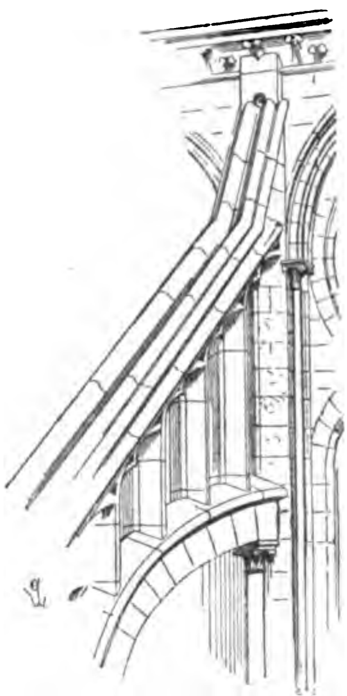

Fig. 89. Flying-buttress, from the Cathedral, Auxerre.

One can deceive with the Roman architecture, because its decoration is only a garment, not always perfectly adapted to the object that it covers; but we cannot deceive with the Gothic architecture, for that architecture is, before all things, a construction.

It is chiefly in the edifices of Ile-de-France that we can show the application of this principle.

We have seen that in Burgundy, thanks to the excellent quality of the materials and to the possibility of extracting them in large pieces, the builders have been able to permit themselves a certain hardihood, which may pass for a feat of strength.

This fault could not be charged against the builders of Ile-de-France or their school. They are wise: they know how to keep

[1] We have often been called upon to defend the projects for restoring Gothic monuments, to give a reason for the expenditures, necessary and considerable, in order to save them from ruin. In the very natural hope of securing economy, people have often repeated: "Do only what is strictly necessary and leave to better times the work of finishing, carving and polishing, etc." The reply was difficult, for it would have been necessary to enforce a whole course of Gothic architecture upon the people who were giving us these suggestions to make them understand that in Gothic edifices everything has to be put together, that the

within the limits imposed by matter and, even when Gothic architecture plunges into exaggeration of its own principles, they still preserve, relatively, that moderation which is the stamp of men of taste.

The valleys of the Seine and the Oise have excellent beds of limestone, but of a slight thickness when the materials are hard and of great thickness when they are soft; that is, at least, the general law. The structures raised in these valleys obey this law.

All the front part of the cathedral at Paris was erected during the first years of the thirteenth century; as a construction, it is an irreproachable work. All the members of the immense western façade, on a scale superior to everything else that was built at that period, are exactly regulated by the dimensions of the materials employed. It is the height of the ledges of stone that has determined the height of all the parts of the structure.

Up to this time, in treating of the early constructions of the Gothic period, we have cited only edifices of moderate dimensions; now, the processes which may be sufficient when it is necessary to build a small edifice are not applicable when it is necessary to raise enormous masses of materials to a great height.

The lay architects of the thirteenth century, consummate workers, thoroughly understood this law, fallen to-day into oblivion, despite our scientific progress and our theoretical knowledge of the strength and the resistance of materials suitable for building.

The Greeks raised only small monuments, in comparison with those of the Roman period, or if, by exception, they wished to surpass the usual scale, it must be admitted that they have not subordinated the forms to this change of dimension. Thus, for instance, the large basilica at Agrigentum, known under the name of the

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stone is laid when carved and polished and that, to speak accurately, one cannot build a Gothic monument while leaving anything to be done by those who are to come after us. From the point-of-view of art, is this a defect? Is it not, on the contrary, the highest praise that could be given to architecture to say, after having proved it, that all which constitutes it is so intimately connected that its ornamentation is so truly part of its structure that one cannot be separated from the other?

Temple of the Giants, reproduces in colossal size the forms adopted in much smaller temples; the engaged capitals of that edifice are composed of two blocks of stone put together. To make an engaged capital by joining two stones set side by side, so that there is a joint in the axis of this capital, is an atrocity in principle. In the same monument, the colossi, who were probably set with their backs to the piers and formed the second inner row, are carved out of courses of stone so thin that their heads contain three pieces.

To make a statue, a caryatid, even if it be colossal, out of courses set one upon another, is likewise an atrocity for a true constructor.

The joints were hidden under a painted stucco which disguised the poverty of the work, very true; from our point of view, putting ourselves in the place of the Gothic builders, the ignorance of the principle is none the less evident.

But one must judge the arts by applying to them their own principles not the principles belonging to different arts. We are not bringing an accusation here against Grecian architecture; only we state a fact and ask that people will judge Gothic architecture by taking its own elements, its code and not by applying to it laws never made for it.

The Romans have only one way of building, applicable to all their edifices, whatever be their dimensions: our readers already know that the Romans *mould* their edifices upon a form, or in a form and cover them with an envelope purely ornamental, which neither adds to nor detracts from the solidity. That is excellent, that is reasonable; but it has nothing to do with Gothic construction, whose appearance is only the result of the structure.[1]

Let us return to our point of departure. We were saying that the Gothic architects of the thirteenth century governed their mode of construction by the dimensions of the edifices that they wished to

[1] We shall perhaps be accused of repeating ourselves in the course of this work; but the prejudices against which we must contend are only the result of error, or of false valuations repeated with rare persistence. In such a case, truth, in order to show its claims, has no choice but to use the same tactics.

erect. There is a law so simple that the whole world may understand it, without having the least idea of statics, namely, that given building stones having a surface 40 centimetres high, for instance, if we raise a pier 3.20 metres high with these stones, we shall have nine horizontal beds in the height of the pier; but if with the same materials we raise a pier 6.40 metres high, we shall have seventeen beds.

If each bed undergoes a depression of 1 millimetre, for the smaller pier the settling will be 9 millimetres and for the larger pier 17 millimetres.

We must still add, to the depression resulting from the number of beds, the greater weight which adds a new cause of settling in case of the large pier.

Accordingly, the more stones the builder piles one upon another, the more he increases the chances of settling, because of fractures or instability in the various members of his edifice, since, if his edifice increases in size, the materials are the same. These differences are not perceptible between edifices that differ little in their dimensions, or when one consents to put an enormous excess of resistance into the constructions; but if one is unwilling to put into the work more than the exact quantity of materials needed and if, with the same materials, he desires to build a façade like that of a village church and one like that of Notre Dame at Paris, he will see the need of adopting special arrangements in the large edifice in order to ward off the singularly increased chances of settling, ruptures and consequent general dislocation.

We have already seen how the early Gothic builders had found a resource against settling and deformations, resulting in the use of stones set upright, against the stratum, to strengthen the higher piers built in courses.

We have also shown how, during the Romanesque period, the builders had enclosed a mass of rough stones between walls that kept on the outside the appearance of a structure in large

facing-stones. The Gothic architects, having been able to show the insufficiency of that process and its lack of cohesion, substituted masonry of small facing-stones and tried to give it resistance and especially rigidity by placing beside it large pieces of stone, detached and only connected from point to point, with the body of the structure, by courses set upon their bed and penetrating deep into that structure. With stones set against the stratum they made columns and with the connecting courses, bases, rings, capitals, friezes and bands. That is the origin of those arcades of the basement, those arrangements of pillars, set against the facings and often even of the open-work which decorates the tops of the exterior buttresses or of the walls.

The façade of the cathedral at Paris furnishes us with fine examples of that mixed construction, composed of courses and of stone inlaid against the stratum, whose function is so plainly evident and which present such brilliant inducements for decoration. One must, it is true, have been called upon to analyze these constructions, in order to recognize their practical meaning; nothing is simpler in appearance, as a structure, than the enormous façade of Notre Dame at Paris and this is one of its excellences. In seeing such a mass, one does not suppose that it is necessary to employ certain artifices, studied contrivances for giving it perfect stability. It seems enough to have piled up courses of stone from the base to the summit and as if that enormous mass ought to maintain itself with its own weight. But, we repeat, to build a façade 20 metres high and to build one 69 metres high are two different operations; and the façade of 20 metres, perfectly solid and well combined, might not, if its dimensions were tripled in every way, be able to stand upright. These are laws which practice alone can teach. There is no need of making intricate calculations to understand, for example, that a pier whose square horizontal section gives 1 metre of surface and whose height is 10 metres, gives 10 cubic metres resting on a surface 1 metre square; that if we doubled the height of the pier and likewise

its width and thickness, although the ratios between its height and its base are similar to those of the first pier, we obtain a surface 2 metres square (or containing 4 square metres) and a solid of 80 cubic metres.

In the first case, the ratio of the surface to the solid is as 1 to 10; in the second, as 1 to 20. The ratios of the weights to the surfaces are hence augmented in a proportion increasing as the scale of the edifice is augmented.[1]

This first elementary rule being established, there is presented in the construction of very large edifices a difficulty which will again augment the effect of the weights produced by the increase in volume.

If the materials do not go beyond a certain height, their dimensions in length and width are equally limited; and it results that, if we can raise, for instance, a pier having a metre of surface in its horizontal section, by means of courses made each of one block of stone, it will not be the same when the pier has 4 square metres in its horizontal section, for we cannot procure courses of that size. Hence, in enlarging the scale of an edifice, on one hand, we change the ratios between the solids or weights and the surfaces; and, on the other hand, we cannot obtain such complete homogeneity in the constituent parts. This is a new cause for rupture — for dislocation. To avoid the danger arising from too great a weight resting upon too small a surface, we are naturally led to enlarge that surface at the base, being at liberty to diminish it in proportion as the structure rises and as the weights consequently become less.

The type most nearly approaching this principle is a pyramid; but a pyramid is a heap of stones, not a construction.

[1] Now, we have sometimes met architects who were greatly surprised to see the piers of their churches breaking down under the weight and who said: "But we followed exactly the relative proportions of such an edifice and used materials analogous as to resistance. Gothic construction really presents no security." One might reply, "No security, it is true, if we wish to enlarge or reduce the scale while preserving the relative proportions. Gothic construction demands that people shall take time to study it and learn its principles and the Gothic architects were wicked enough to invent a system of construction which, in order to be applied, must be studied and reasoned out."

Let us suppose a tower built on four walls, and shown in cross-section in Figure 90. We have given to the walls at the base a thickness sufficient to resist the pressure of the upper portions and, as much to reduce that pressure as to keep from piling up useless

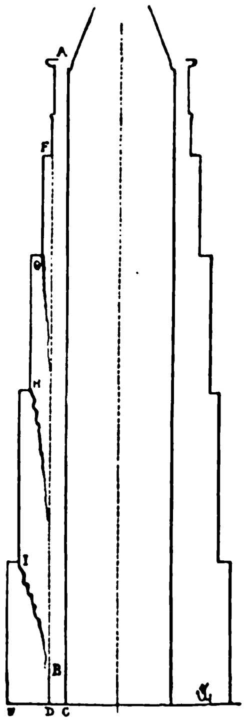

Fig. 90.

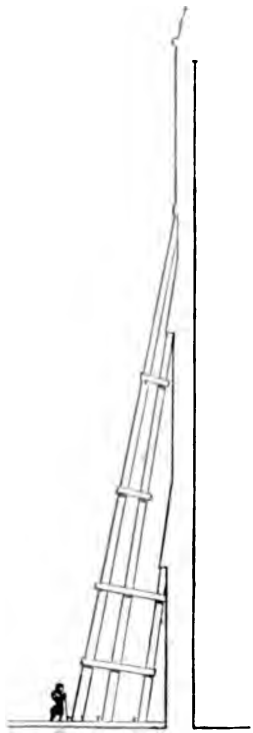

Fig. 90*b*.

materials, we have gradually reduced the thickness of these walls, accordingly as our structure has risen. But, plainly, all the weight *A B* rests upon the surface *C D* and if the additional weight *D E F* is not perfectly united with it and does not form a whole with the load *A B*, from top to bottom, since the most important settling

must take place from A to B, fractures will occur, first at I, then at H, then at G; this increment of weight $D\ E\ F$ that we have added, will do more harm than good and since all the pressure will then bear effectively upon the surface $C\ D$, the inner facing of the wall will give way. If our tower is not very high, it will be easy for us to fasten together perfectly, by means of long stones, the outer facings to those within, to make a homogeneous structure and hence it will be really the base $C\ E$, which will carry all the weight; but if our tower is very high, if its size is colossal, whatever precautions we may take, since the structure must consist of a considerable quantity of stones, we shall never be able to fasten the two facings together firmly enough to resist that difference of pressure exerted on the interior and exterior; our masonry will come apart and the effects just noted will be produced. We must hence use some artifice. We must bring it to pass that the outer facing, less heavily weighted, shall present a rigidity greater than that of the inner facing and that at the height of each point of retreat there shall be a very strong connection with the body of the structure.

In other terms, the outer facing must prop the body of the masonry and produce the effect seen in Figure 90*b*.

Now, this is not easy when we have only stones nearly all of the same size. Still, the architect of the façade of the cathedral at Paris has reached this result by a very scientific and well planned arrangement of his structure. He has begun by establishing each tower, not upon filled walls, but upon piers (see plan of the cathedral of Paris under the word "*Cathédrale*"), for it is easier to give homogeneity to the structure of a pier than to that of a wall.

These exterior and interior piers are built in courses of hard stone, regular, carefully levelled, enclosing an excellent mass and consisting of large stones sunk in thick mortar.

The interior pier is buttressed in every direction, since it is interior and it carries a vertical weight; but the exterior piers, whether at the front or the sides, have had to be supported by a

strong base. Now, the whole structure is well faced in long stones, within and without and from the basement to the shaft of the towers the supports are built as indicated in Figure 91.

The result of the method employed is that, although a much stronger pressure is exerted upon the inner facing (whose intersection with the projecting jambs of the bays at different heights is shown by the dotted line *A B*) than upon the exterior facings of the piers and although, because of this pressure, a perceptible settling can be seen in the interior, nevertheless, since all the weights are transmitted, by the arrangement of the blocks of stone sunk in the thickness of the filling and fastened by cramp-irons at different heights, upon the outer facing and since they form, as indicated in Figure 91*b*, a series of angles like the teeth of a saw, the weight *C D* rests upon the base *E F*, the weight *E G* rests upon the base *I K*, the weight *I L*, upon the whole base *M N* and thus down to the base of the pier.

But since, in fact, the depression must take place between the points *E G*, *I L*, *M O* and *P R*, it results that the projections *G F*, *L K*, *O N*, *R S*, rest their angles *F*, *K*, *N*, *S*, very heavily upon the outer facing *V*, and since this undergoes less depression than the inner facing, being less heavily weighted, it fills the office of the prop that we indicated in Figure 90*b*.

To-day when we no longer build these colossal structures, consisting of widely varying parts, we do not suspect the effects manifested under such circumstances and we are very much astonished when we see them taking place and causing the most serious disorders. It is easy to reason theoretically about these enormous weights unequally distributed; but in practice, through lack of precaution in details and through abandoning the execution to the methods of habit, we are reduced very frequently to acknowledge our weakness, to blame the art that we profess, the soil on which we build, the materials, the contractors, everything and everybody except the perfect ignorance in which we have been left, under pretext of keep-

Fig. 91.

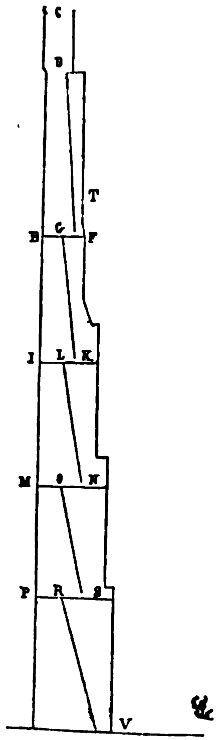

Fig. 91 *b*.

ing up the classic traditions. We admit freely that the architecture of the Romans was superior to Gothic architecture, so much the more freely since, to us the architecture of the Greeks, of the Romans, or of the western nations of the Middle Ages, is good from the moment that it remains faithful to the principles admitted by each one of these three civilizations; we will not dispute about a matter of taste.

But if we wish to erect monuments like those of ancient Rome, we must build as the Romans built; have space, slaves, a powerful will; be the masters of the world, impress men and take materials where-ever it shall seem good to us. . . . Louis XIV played the part of a Roman constructor seriously, even to sometimes pretending to build like a Roman. He commenced the aqueduct of Maintenon like a true emperor of the ancient city; he commenced, without being able to finish. Money, workmen and more than all that, the imperious need, were wanting. In our great railroad constructions we also approach the Romans and this is the best that we can do; but as to our domestic constructions, the monuments or the dwellings in our cities, when we pretend to ape the Romans, we are only ridiculous and we should act more wisely, it seems to us, in profiting by the elements used among us with reason and success by generations of artists, who have admitted principles agreeing with our needs, our means, our materials and the modern spirit.

We have now said enough about the construction of the Middle Ages to make clear wherein its principle differs entirely from the Roman principle of construction, how the processes that suit the one do not suit the other and how the two methods are the result of opposite civilizations, ideas and systems.

Having admitted the principle of equilibrium, of active forces opposed one to another to produce stability, the builders of the Middle Ages, because of the natural tendency of man toward abuse in everything, could not but end by exaggerating, in the successive applications of these principles, whatever they might have that was

good, rational, or ingenious. Still, we repeat, the abuse is felt less in the provinces of the Royal domain and particularly in Ile-de-France, than in the other countries where the Gothic system had penetrated.

It is easily seen that so early as the middle of the thirteenth century the builders were perfectly at ease among these problems of equilibrium so difficult to solve in edifices of very great size and often of very frail materials.

In the North they built only in stone, but they employed at the same time and in the same edifice facing stones in courses set upon their natural bed, the large stones sunk in mortar, an easily compressible mass and the blocks set against the stratum, rigid, inflexible props, that might in certain cases be of great assistance. Elasticity being the first of all the necessary conditions in monuments erected on slender supports, it was still necessary to find, besides that elasticity, absolute rigidity and resistance. It is through lack of the power or the will to apply this principle, in all its exactness, that the Cathedral of Beauvais could not be maintained. There, elasticity is everything. That monument may be compared to a wicker cage. . . . But we shall return to it later, for its faults are an excellent lesson. . . . Let us not leave so soon our Cathedral of Paris. The section of one of the buttresses of the towers shows us clearly that the builders at the beginning of the thirteenth century did not pile the stones one upon another without purpose and without noticing the effects which were produced in large edifices, in accordance with the laws of weight. Their masonry lives, acts, fulfils a function, is never an inert and passive mass. To-day we build our edifices somewhat as a sculptor makes a statue: provided the human form is passably observed, it is enough; but it is none the less an unorganized block.

The Gothic building has its organs and its laws of equilibrium and each of its members coöperates with the whole by an action or a resistance. Every one cannot see the interior of the buttresses of

the towers of Notre Dame at Paris and we foresee an objection that has often been addressed to us, namely, that our imagination has led

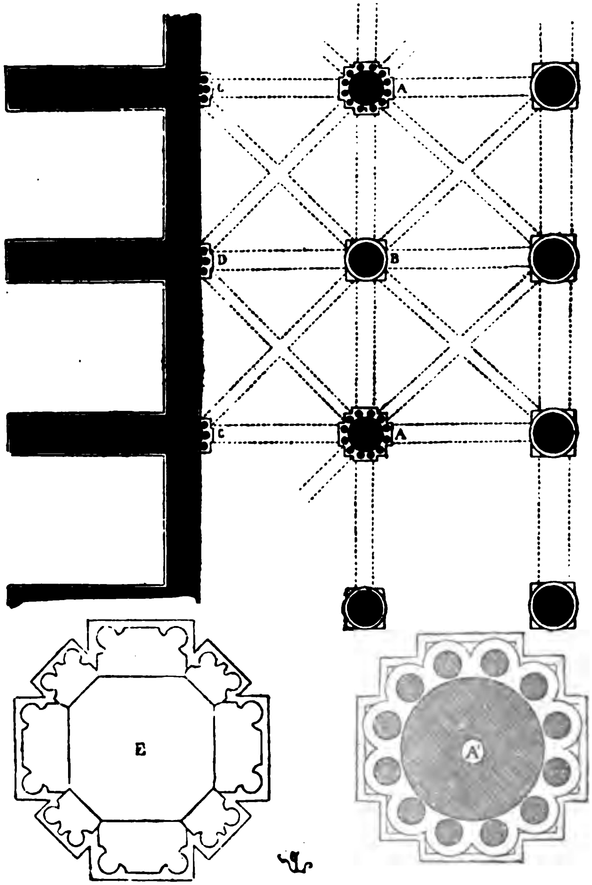

Fig. 92. Double Aisles of Nave, Cathedral of Notre Dame, Paris.

us to attribute to these artists of past centuries intentions that they never had. So let us take for the benefit of these doubting spirits an

instance that they can easily verify in this same monument. The great vaults of the nave in the Cathedral of Paris are composed, as every one can see, of diagonal arches including two compartments and intersected by a transverse arch; it is the early system of Gothic vaults explained in detail in this article.

The result of this arrangement is that the piers of the great nave are unequally loaded, since they receive, alternately, either a transverse arch alone, or a tranverse and two diagonal arches; and yet the piers of the great nave are all of equal diameter. This is something of a shock to the reason, especially in a very large edifice since these unequal weights ought to produce unequal degrees of settling and since, if the piers supporting three arches are strong enough, those supporting only one are too strong; but if, on the contrary, those supporting only one arch are of a suitable diameter, those which support three are too slender. Apparently there is no answer to be made to this criticism and we must admit that it took us a long time to explain such apparent disregard of the simplest principles among artists who always proceed by reasoning.

Nevertheless, this is a proof that we must never be hasty in passing judgment on an art that we are scarcely beginning to decipher. Let us enter the aisles of the cathedral, double in the nave as about the choir; but let us remark in passing, that this nave was built fifteen or twenty years after the choir and that the architects at the beginning of the thirteenth century, who built it, profited by mistakes made by their predecessor.

We notice that the piers which separate the double aisles of the nave are not all alike. We see alternately a monocylindrical column consisting of courses (drums) of stone and a central column also consisting of courses, but flanked by twelve small columns, each in one piece and set against the stratum. (See plan, Fig. 92.)

Why this difference in construction? . . . Is it caprice — a whim?

But however little one may have studied these monuments, he remains convinced that caprice has no share in the plans of the

builders of that period, especially in case of such an important member in architecture as a pier.[1]

The question, "Why that difference?" being put, we shall with some care soon solve it.

These intermediate piers *A*, surrounded by pillars set against the stratum, are coupled with the pillars of the great nave, which support the heaviest weight, namely, one transverse and two diagonal arches. Now, we must know that originally the flying-buttresses of the nave were not those which we see to-day and which date only from the second half of the thirteenth century. These original buttresses were in double flight; that is, they first rested on an intermediate pillar placed upon the piers *A* and *B* of the double aisle and then were buttressed in their turn by secondary flying-buttresses clearing the spaces *A C* and *B D*. (See the word "*Cathédrale*," Fig. 2, giving the sections of the nave of Notre Dame at Paris).

Certainly the flying-buttresses destined to balance the transverse and diagonal arches of the great vaults were stronger than those destined only to balance a simple transverse arch scarcely weighted. Perhaps even the intermediate transverse arch of the great vaults was not balanced by a flying-buttress, which would not have hindered the vaults from keeping their curvature, since, in the two transepts, we still see simple transverse arches thus left to themselves without undergoing deformation. The previous explanations contained in this article have shown that the vertical pier carrying the vaults plays only a subordinate part and that a great part of the weight of the vaults, being drawn off by the flying-buttresses, rests upon the abutment of these flying-buttresses.

Hence it was reasonable to give to the pillars destined to carry the piers on which rested the flying-buttresses, or at least the more

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[1] Caprice is an explanation admitted in many cases, when one speaks of Gothic architecture; it has the advantage of reassuring the consciences of those who would rather cut through a difficult question with one word than try to solve it.

powerful flying-buttresses, a greater resistance. But had the architect given greater diameter to the piers *A* than to the piers *B* (Fig. 92), these pillars *A* would still have been compressed by the very heavy weight that they had to support and their settling would have occasioned very serious disorders in the higher structure, the rupture of the flying-buttresses and hence the deformation of the great vaults. Still, the architect did not wish to give to these pillars *A* such a thickness as to render difficult the building of the vaults of the aisles and to produce an unfortunate effect; so he has, as usual, employed an artifice; he has surrounded his cylindrical piers, built in courses, by strong columns set against the cleavage — twelve resisting, incompressible supports (Fig. 93), with the certainty that this system of building could undergo neither settling nor deformation and that consequently very strong flying-buttresses, resting upon these piers, could undergo no displacement. This arrangement had also the advantage of leaving above the capitals, between the transverse and diagonal arches, a strong course *E*, resting directly upon the central column *A* (Fig. 92).

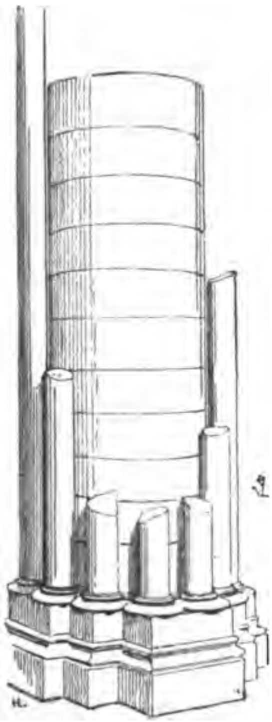


Fig. 93. Aisle Pillar, Notre Dame, Paris.

The method of laying the materials (stones) either upon their natural bed, or perpendicularly to it, was rapidly improved during the first half of the thirteenth century. In this, there was, in fact, a means to which we, who claim to have invented everything, resort every day, since we use cast-iron in our

constructions with much less intelligence, we repeat, than that shown

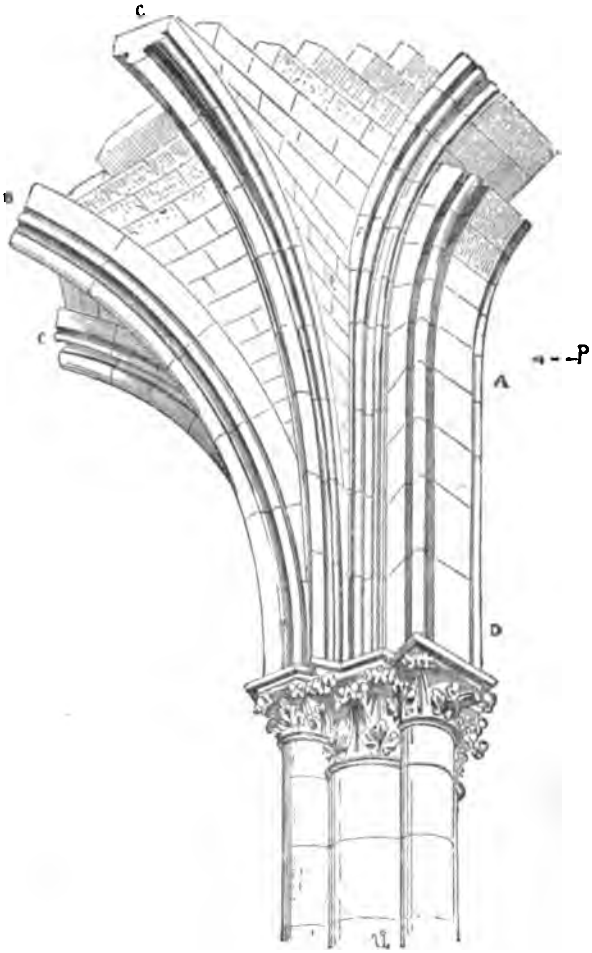


Fig. 94. Vaulting in Chancel, Notre Dame, Amiens.

by the Gothic builders when they sought to obtain incompressible and rigid supports by the use of certain stones of excellent quality.

Let us see other applications of these principles still better reasoned out.

The choir of the Cathedral at Amiens, built some years before that at Beauvais, is, from the point of view of Gothic construction, a masterpiece, particularly in the lower parts.[1]

Let us first examine the piers of the chancel of Notre Dame at Amiens. These piers give, in their plan, a large cylindrical column 120 centimetres in diameter, flanked by four columns, three of which are 45 centimetres in diameter and one 35 centimetres. These four columns are built only one-fourth part into the central cylinder. The abaci of the capitals are made to receive exactly the arches of the vaults, as appears in Figure 94, and the contours of these arches are themselves shaped with reference to their functions.

The archivolts *A* consist of a double row of voussoirs and support the wall.

The transverse arches *B* of the aisles, which sustain only the vault and prop the structure, have a more slender contour and their whole resistance is upward, like a groin or a rib.

The diagonal arches *C* are shaped after the same principle, but narrower than the transverse arches, their burden being lighter and their function less important. A single stone of impost, the first one *D*, has its upper bed horizontal; above this stone each arch detaches itself and is formed of independent voussoirs.

It will be observed that the triangles *E*, filling the vaults, rise vertically to the point where their meeting with the extrados of the second arch *F*, serving as wall-arch, permits them to follow its curve.

If we suppose a horizontal section of this structure at the level *P*, we obtain Figure 95, on which we have traced with white and dotted lines the alternate arrangement of the courses.

At *S* is a structure, solidly built, not of rough stones, but by

[1] See the word "*Cathédrale*" for the historical outline of the structure of Notre Dame at Amiens. The upper parts of the choir could be finished only with insufficient resources.

means of courses piled up to form a support and to balance the pier supporting the upper gallery.

If we cut the pier vertically through its axis *M N*, we shall have the section (Fig. 96).

A is the level of the capitals at the beginning of the vaults of the

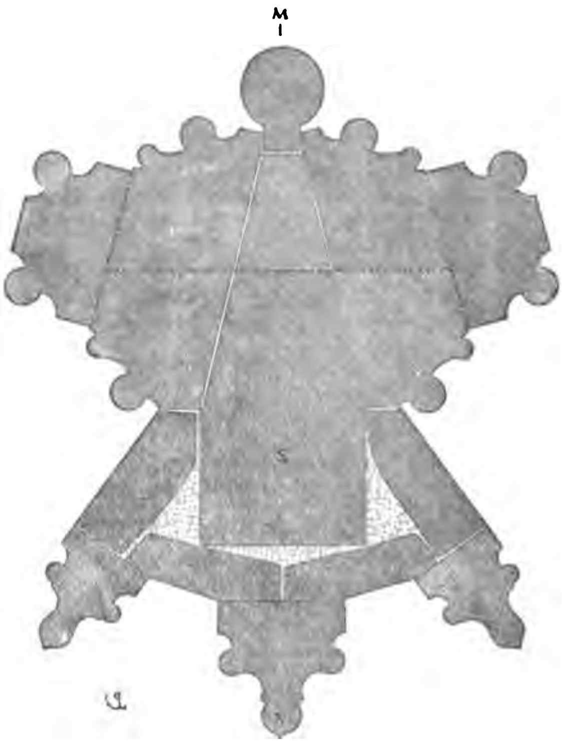
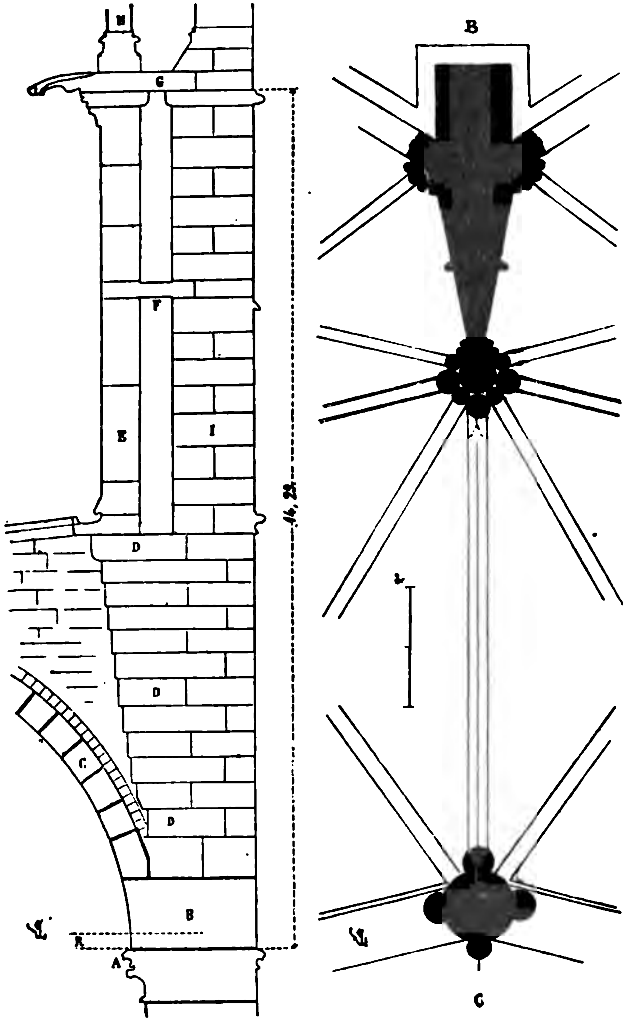


Fig. 95.

aisle; *B*, the impost of these vaults with its temporary tie-rod *R*, placed there only during building in order to keep the piers in position and check the lateral thrust of the arches until these piers are weighted [see "*Chaînage*"]; *C*, the transverse arch, which is



Figs. 96 and 97. From the Chancel of Notre Dame, Amiens.

free; *D*, the courses projecting in corbel to receive the buttress *E* of the gallery above the aisle.

This buttress, built of large pieces of stone set against the stratum, is joined to the principal pier *I* by an intermediate lintel *F*.

In *G* is the course forming a roof for the gallery, an upper passage on a level with the supports of the high windows and a connection between the two piers.

At *H* is the detached column, built like the buttress of great pieces of stone and consequently rigid, which sustains the top of the flying-buttress.

The whole burden is thus brought upon the pier *I*, first, because from that pier start the arches of the vaults and next, because since the pier *E*, as well as the column *H*, is composed of stones set against the stratum, the settling and the weight are hence produced upon that pier *I*.

This weight being much greater than that resting upon the pier *E*, it results that the courses *D*, forming a corbel, completely destroy any tendency to sway or bend, on the part of the buttress *E*.

The transverse arch *C* is free and can not be put out of shape by the pressure of the piers *E*, since that does not act upon its haunches.

This construction is very simple: still it had to be discovered; but the following fact shows the extraordinary sagacity of the architects of this remarkable part of the Cathedral at Amiens.

The aisles and radiating chapels of the circular part of this edifice give, in horizontal plan above the bases, Figure 97.

The flying-buttresses that balance the thrust of the upper vaults are in double flight, or, in other words, they rest upon a first pier set upon the cluster of columns *A* and upon a second pier set upon the abutments *B*.

Cutting through *C B*, these flying-buttresses present the outline (Fig. 98). This section shows clearly that if the weight bearing upon the piers *C* is considerable, that bearing upon the piers *A* is still greater, since it is active and produced not only by the weight

Fig. 98. Chancel Buttress, Notre Dame, Amiens.

of the pier *D*, but by the pressure of the flying-buttress. Every structure built in courses settles down, and this settling is the more marked, as the weight is heavier.

Any settling that takes place in the piers *C* will not bring us danger so long as the piers *A* settle less, for by examining Figure 98 we shall see that the lowering of the pier *C* by several millimetres, if the pier *A* resists, will result only in pressing the flying-buttress harder against the haunches of the high vaults and in fastening the whole structure together with more power, by pressing it towards the interior, which cannot be put out of shape from without, since it is in the form of a polygon; but the pier *A* must not settle as much as the pier *C*.

The whole resistance of the structure depends upon this condition. Now, the following is the manner in which the builders have solved the problem:

The piers *C* have been erected in courses separated by thick joints of mortar, according to the method of masons at that period; the piers *A* are on the contrary composed of groups of columns built of large pieces of stone, a species of posts (to borrow a term in carpentry), which cannot settle like a quantity of courses set in beds of mortar.

Not wishing to give to these piers *A* a broad impost, in order not to obstruct too much the entrance to the chapels, they find no better means to make them very rigid under the weight that they have to support than to compose them of a group of almost monolithic columns and in thus diminishing the number of joints, to remove every cause of settling.

Let us notice that the materials at the disposal of the architects of Picardy can be set with impunity against the cleavage and that if they have erected these columns of the piers *A* in several pieces it is because they could not procure monoliths ten metres high; they have taken the largest stones that they could find, varying between one and two metres, while the piers *C* are built in courses from fifty to sixty centimetres high.

At Amiens, theory and practice have conquered the difficulties presented by the building of a nave fifteen metres wide, from axis to axis of the piers, by 42.50 metres of height under the key and flanked by aisles seven metres wide by nineteen metres high under their key.

This vast construction has kept its position and the movements

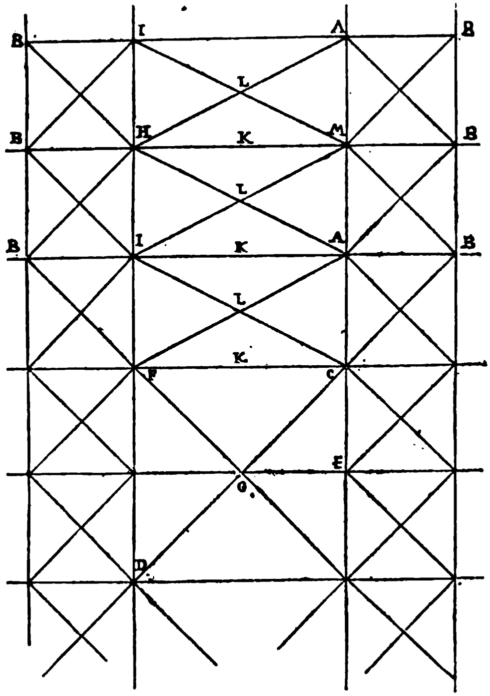


Fig. 99.

which must necessarily have taken place in so extensive a building have not been able to alter its solidity.

Then architects had given up crossed vaults having two compartments; for, wishing to distribute the thrusts equally among the points of support, separating these compartments, they had adopted after 1220 oblong vaults with diagonal arches, in accordance with

the plan (Fig 99). This was more logical, for the piers *A*, *M*, *I*, *H*, were equal and the supports *B* all alike and the flying-buttresses of the same strength.

The builders were now coming to formulas: their artistic feelings must have been shocked by these vaults crossed over double compartments and appearing to throw their weight upon alternate piers and whose diagonal arches *C D*, by their inclination, had concealed the windows cut from *C* to *E* under the wall-arches.

Furthermore, as we have already said, these diagonal arches, having a diameter *C D* very long in comparison with the diameters of the transverse arches *C F*, obliged them to raise the keys *G* considerably; which interfered with the laying of the tie-beams of the trusses, or necessitated considerable raising of the copings of the wall-arches *C E*.

In building the vaults with diagonal arches in compartments, the diagonal

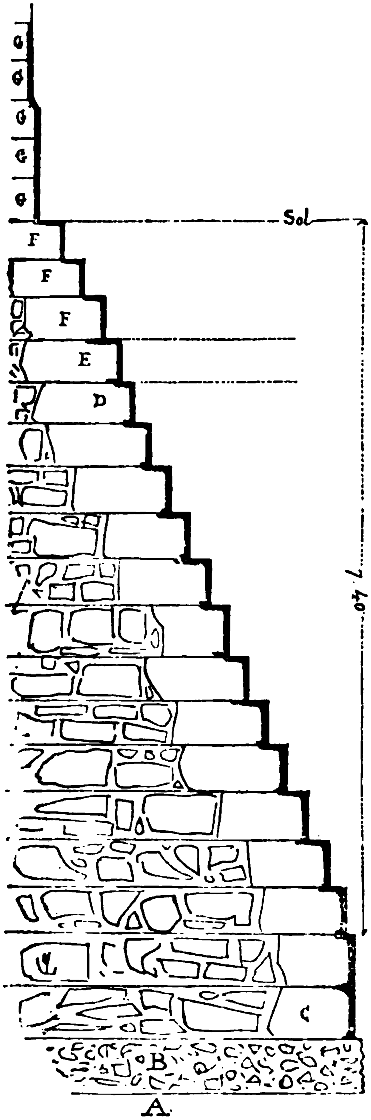


Fig. 100.

arches $A\ H$ being semicircular, it was easy to keep the keys L of these diagonal arches from rising above the level of the keys K of the transverse arches $A\ I$ and $M\ H$, which were in tierce-point.

Our readers are now able, we believe, to understand in general, as well as in detail, the building of a large church in the thirteenth century, such as, for example, the Cathedral of Beauvais.

In order to avoid repetition and to gather up the scattered methods of which we have just been giving an idea, we shall follow step by step one of those great constructions from the foundation even to the timbers of the roof. If we choose the Cathedral of Beauvais, it is not because that edifice is perfect as to execution, but because it is the truest and most absolute embodiment of the theory of the builder at the middle of the thirteenth century.

Part of this edifice fell down less than a century after the completion of the choir; and yet it was designed in such a way as to enable it to stand for centuries. This disaster, which has completely altered its character, was due to indifferent execution, the lack of rigid supports, or their too slight resistance and especially to the nature of the materials, which were neither large nor solid enough. If the architect of the choir at Beauvais had possessed the materials of Burgundy, those used at Dijon and Semur, for instance, the excellent lime-stones of Chatillon-sur-Seine, or yet the stone of Montbard, of Anstrude, or of Dornecy, or even, as might have been possible, the stone of Laversine, of Crouy and of certain hard ledges in the valleys of the Oise, or of the Aisne, the choir of Beauvais would have remained standing.

The master-builder at Beauvais was a man of genius, who wished to reach the utmost limits possible in the use of building-stone; his plans were correct, his arrangements profoundly learned and his conception admirable; but he was badly seconded by his workmen and the materials at his disposal were insufficient. His work is none the less a very valuable subject for study, since it furnishes us with the means of learning the results which the thirteenth-century method of construc-

tion could reach. We have given in the article "*Cathédrale*" (Fig. 22) the plan of the choir of Beauvais. This plan, if compared with that of the Cathedral of Amiens, shows that the two parallel compartments near the piers of the transept are narrower than the two following; the builder thus avoided too active thrusts upon the two piers of the transepts forming an entrance to the choir. As to the two following compartments, they are unusually wide, almost 9 metres from axis to axis of the piers. The need of giving free spaces is so evident at Beauvais that the piers of the circular space are not joined by pillars at the sides to receive the archivolts, but only in the manner of radii of the apse, to receive the groins of the great vaults and the transverse and diagonal arches of the aisle.

In conformity with the method of the builders of that period, when they are not led aside from their theory by questions of economy, the foundation of the choir is admirably built. The chapels rest upon a solid circular masonry, covered by facing-stones, as in the Cathedral of Amiens and presenting on the outside a strong water-table, likewise faced in large stones, carefully dressed and set in thick beds of mortar. This base of solid masonry is connected with the wall supporting the detached piers of the chancel by radiating walls under ground.

In the Cathedral of Amiens, wherever we have been able to examine the foundations clear to the bottom, we have found, on the outside, the profile, Figure 100.

At *A* is a course of clay, 40 centimetres thick, set upon the natural clay. At *B* is a bed of concrete 40 centimetres thick; next, from *C* to *D*, 14 courses from 30 to 40 centimetres thick, each of stone obtained from the quarries of Blavelincourt, near Amiens.

This stone is a mixture of chalk and silica and very strong, so that it can be cut out in large pieces. Above this we find a course *E* of stone from Croissy, then three courses of sandstone under the outer earth. Above the ground level, the whole building rests upon six more courses of sandstone, well faced and of extreme hardness.

Behind the facings of the foundation is a mass of large fragments of silex stone from Blavelincourt and Croissy, sunk in a very hard and well-made mortar. It is upon this artificial rock that the immense cathedral rests. At Notre Dame at Paris the foundations are likewise built with the greatest care and faced in strong ashlar of great thickness, the whole resting upon solid soil — that is, upon the lower sand of the Seine, which is in large grains of a greenish color. As for the piles which people pretend exist under the masonry of most of our great cathedrals, we have never found any traces of them.[1]

Now let us return to Notre Dame of Beauvais.

We have given in the article "*Arc-Boutant*" (Fig. 61) the general view of the system adopted for the building of the flying-buttresses of the apse of the Cathedral of Beauvais. We must return to the details of this construction and it will be seen how the builder of this choir tried to surpass the work of his fellow-architects at Amiens. Yet these two apses were built at the same time, that of Beauvais perhaps being later by some years. We suppose, just as we have done for a flying-buttress in the choir of Notre Dame of Amiens, a section made through the axis of the piers of the apse at Beauvais. (Fig. 101). It is interesting to compare these two sections; we therefore give them on the same scale. At Amiens, the piers of the chancel are 14 metres high from the pavement of the aisle to the abacus of the capitals supporting the vaults of the aisles. At Beauvais, these same piers are 15.90 metres. But at Amiens, the absidal chapels are as high as the aisle, while at Beauvais they are much lower and between the platforms that cover them and the vaults of this aisle there is a gallery, a triforium *F*. At Amiens it is the intermediate pier which has the passive rigid

[1] It is with these piles, at Notre Dame at Paris and at Notre Dame at Amiens, as with so many other fables that have been repeated for centuries about the building of Gothic edifices. It would be impossible to build a great cathedral on piles. These edifices can be founded only upon broad bases; the loads being very unequal in amount, the first condition of stability is to find a perfectly homogeneous and resistant mass under ground.

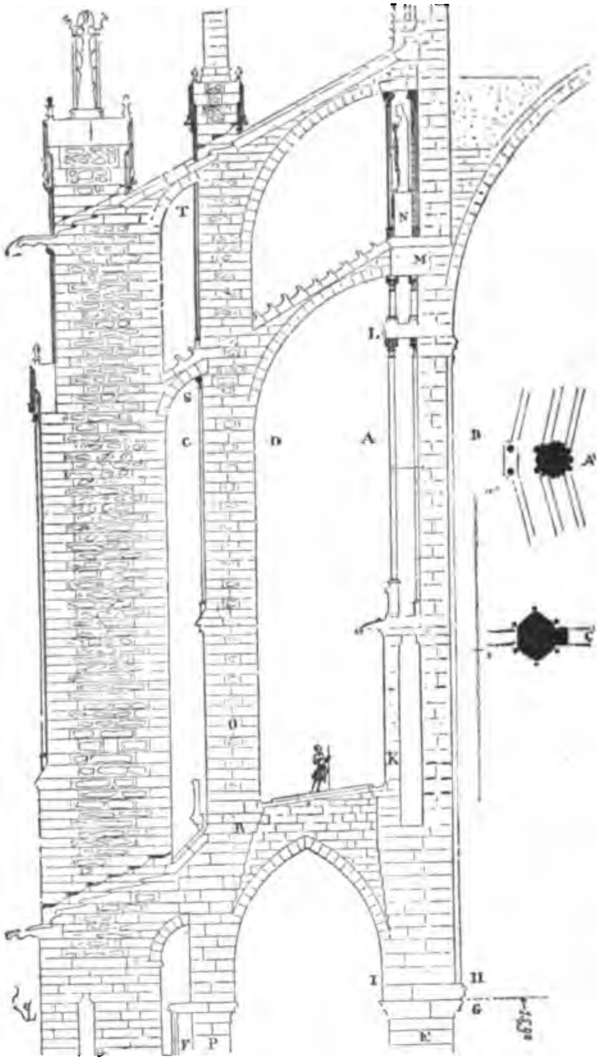


Fig. 101. Flying-Buttresses at Beauvais.

resistance, thanks to its mass and to the manner of building the lower piers, as we have just shown; the second pier is only an accessory, a surety, an additional though necessary precaution.

At Beauvais the master-builder tried to give this intermediate pier an active resistance and to bring to the second pier, the exterior one, the passive resistance which he must always find somewhere. He expected thus to be able to secure more lightness in the general effect of his structure, more height and more solidity. As we have already said, the piers *E* of the chancel have more space, are thicker than those at Amiens, in the direction of the thrusts.

The groups of pillars carrying the diagonal and wall arches of the high vaults are set in corbel-form upon the lower capital *G*.

The impost *H I* is hence greater and the pier *K* of the large triforium rests vertically upon the lower pier.

Upon this pier *K* of the triforium there is no longer one column, as at Amiens, to receive the end of the flying-buttress, but two smaller columns set against the cleavage, as seen by the horizontal section *A'* made through *A B*.

These two columns sustain the lintel *L*, which is a course acting as ceiling. Two other columns are set between this lintel-course and the top of the flying-buttress, which rests against an enormous block *M* of stone, weighted by a course, as cornice, and a pedestal *N* supporting a colossal statue.

Another pair of pillars is placed in front of this statue, between the first and the second flying-buttresses. These latter pillars support, not the top of that flying-buttress, but a pinnacle whose form and structure we shall at once point out. This whole system closely resembles that which we have seen at Amiens. Yet we notice that the whole method of double building exerts a vertical pressure upon the lower pier, whose interior is built in courses and its exterior in large, rigid pieces, set against the cleavage, to give firmness to the structure at once so slender and so tall; we notice, too, that the strong lintel *L*, the block *M* and its burden *N* tend evidently to add

considerable weight to the top of the support below, in order to keep it vertical and make good its function of stanchion.[1]

Hence the inner pier is made as rigid as possible, for it is now necessary to resist the thrust of the vault, acting from an enormous height.

The architect felt unable to get along with a single flying-buttress, as at Amiens, even were it surmounted by a rigid open-work; he was right, for at Amiens, in the parallel parts of the choir which received three vault-groins instead of one, these flying-buttresses with open-work were displaced by the pressure of the vaults and in the fifteenth century it was necessary to build new flying-buttresses under those of the thirteenth. But the master-builder of Beauvais here evinced an unparalleled hardihood and at the same time a rare sagacity. It is seen that the intermediate pier *O* does not rest squarely upon the pier *P*, the summit of the chapel, as in the Cathedral of Amiens, but that its axis is in the same vertical with the inner facings of that pier *P*.

Let us say at once that this pier *O*, whose horizontal section through *C D* we give at *C'*, has greater weight in its side *C* than on the side *D*. Its centre of gravity is then inside of the dotted line *R*, or, in other words, above the pier *P*.

Still the pier is thus in equilibrium and tends to incline towards the interior of the church rather than toward the large outer buttress; it succeeds, then, by its position: first, in drawing off the thrust of the two flying-buttresses, secondly, in adding to the resistance opposed by these flying-buttresses a tendency to incline toward the choir.

The vertical pier *O* thus does the duty of an oblique prop. If this active resistance does not suffice (and it cannot suffice), the pier *O* is in its turn sustained in its function by the two secondary

[1] In the fourteenth century the columns placed upon the triforium had become broken and there was placed instead of them a solid pier (See Fig. 61, article "*Arc-Boutant*"); but it is still possible to-day to recognize their position and approximately their diameter.

flying-buttresses *S* and *T* and by the large passive buttress. But, some one may object, why this intermediate pier? Why do not the large flying-buttresses rest simply upon the large passive buttress without?

It is because the large outer pier could not buttress the thrust of flying-buttresses of so great radius, without being doubly augmented

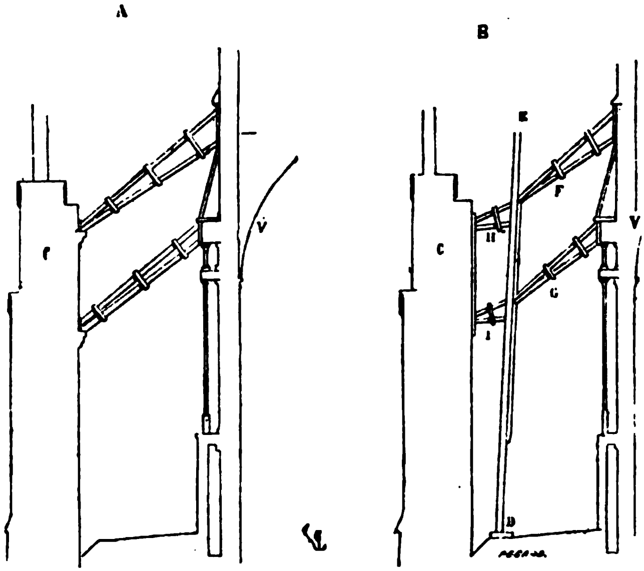


Fig. 101*b*.

and because, thanks to the intermediate pier *O*, it has only to buttress a pressure that is diffused and almost annulled.

To explain clearly the function of the pier *O*, let us suppose that we have to put props under the choir of Beauvais and let us suppose that we have only the large buttress to place our props upon.

If (Fig. 101*b*) we set our props as indicated in *A*, we shall surely overturn the pier *C*; but if against the pier *C* we place, according to the drawing *B*, an intermediate prop *D E*, slightly

Fig. 101c. Flying-Buttresses, Choir of Beauvais Cathedral.

inclined toward the choir but kept in a vertical plane passing through the axis of the piers or the radius of the chancel and if from that prop we extend two supports *F* and *G* against the vault and then two others at *H I*, we shall no longer need to fear the effect of the thrusts of the vaults *V* upon the great buttress *C*, for the intermediate prop *D E* will draw off a large part of the thrust by the two supports *F G* and will transmit it to its base *D*. This is the whole problem given and solved by the architect of the choir at Beauvais. Unhappily, the execution is defective. Still, it is certain that this immense edifice would have kept perfect stability if the architect had made the two pillars above the triforium stronger and more resistant, if he could have made them of cast-iron, for instance. The disorders which have occurred in the structure have all come from this; these columns, too slender, have given way, for they could not resist the weight brought upon them when

the inner piers began to settle in consequence of the drying of the mortar. In the disorder the lintels *L* (Fig. 101) were broken, the large blocks *M*, in swaying, rested too heavily upon the top of the first flying-buttress; this latter was thrust out of shape and, the vault following the movement, the pressure upon these flying-buttresses was such that they nearly all were forced outward and their action annulled, while, in consequence, the upper flying-buttresses were loosened somewhat, since the vault no longer pressed against them. The equilibrium was broken; and considerable labor was needed to avoid the total ruin of the edifice.

Figure 101*c* gives in perspective the summit of the piers receiving the tops of the flying-buttresses and shows us clearly that the intention of the master-builder was to obtain at the height of the piers of the choir of the Cathedral of Beauvais and under the flying buttresses, supports not solid, but perfectly rigid, in order, first, to load the lower piers as little as possible; and secondly, to make the settling of the interior parts, built in courses and stiffened by the pillars set against the stratum, naturally carry the weights inward. From this example and from those belonging to Gothic construction properly so-called, there is derived this principle: that every structure built of courses set upon one another in large quantities must be supported and made rigid by the addition of monoliths surrounding, flanking and sustaining the piers composed of courses. This principle is scarcely applied by the Romans, who had no need to resort to it; it belongs to the Gothic builders. From this principle they make one of the most ordinary *motifs* for the decoration of buildings and, in fact, it lends itself to the most brilliant and daring arrangements.

It is true, that, in the example of construction just given to our readers, there are grave defects and we do not disguise them. That outer scaffolding of stone, which forms the whole strength of the building, is subjected to the action of the atmosphere; it seems as if the builder, instead of trying to protect the vital parts of his

structure, had taken pleasure in exposing them to all the chances of destruction. His system of equilibrium depends upon the absolute resistance of materials too often imperfect. He evidently wishes to astonish and he sacrifices everything to this desire.

But beside these grave defects, what profound knowledge of the laws of equilibrium! what subjection of matter to the ideal! what a theory, fertile in applications! Let us never imitate these subtile constructions, but let us profit boldly by the acquisition of so much knowledge. But to profit by it, we must cultivate and exercise it.

In the article "*Chainage*" we have shown what were the processes used during the Middle Ages for anchoring the edifices. For the long beams of wood, used during the Romanesque period, the builders of the thirteenth century, seeing that these soon decayed, substituted cramp-irons uniting the stones composing the courses. This method was never, at any time, employed with such singular exaggeration as in Ile-de-France. There are edifices, like the Sainte-Chapelle-du-Palais at Paris, where all the courses, from base to summit, are fastened by irons. At Notre Dame in Paris even, it is seen that all the structures raised or repaired after the early years of the thirteenth century are, at heights not far separated, fastened by cramps set in lead. Certainly these builders had not entire confidence in their very ingenious devices and their innate good sense made them soon feel that they were carrying their boldness too far. The way in which these anchorages are arranged shows, moreover, that what they feared most was the bending or twisting of the piers and walls; and in that regard the system of stone posts adopted by the Burgundian architects had a marked superiority over the dangerous use of cramp-irons sealed up in solid masonry. It must also be said that the builders of Ile-de-France found difficulty in procuring long stones resistant enough and capable of being set with impunity against the cleavage, while in Burgundy these were common and of excellent quality.

It is time now to introduce our readers to an edifice which, in

itself alone, embodies and at the same time skilfully exaggerates all the theories of the builders of the Gothic school. We refer to the church of St. Urbain of Troyes.

In 1261, Jacques Pantaléon, a native of Troyes, was chosen pope, under the name of Urbain IV, at Viterbo; he died in 1264. During

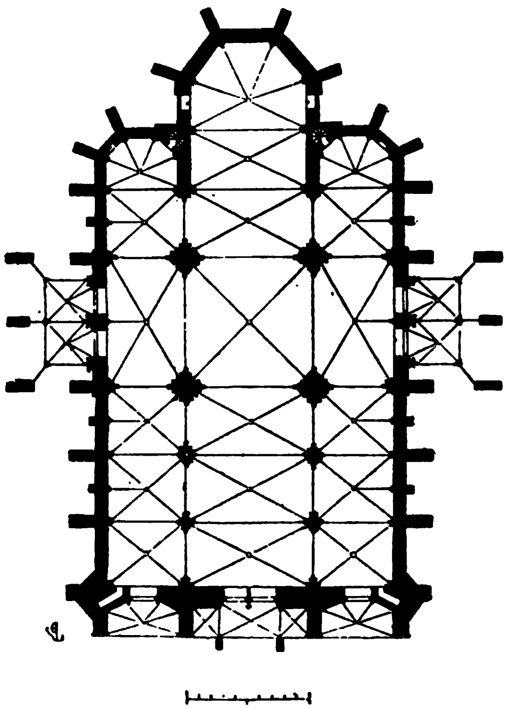


Fig. 102. St. Urbain, Troyes.

his pontificate, he wished to erect at Troyes a church under the name of St. Urbain; so this monument was begun and rapidly progressed; nevertheless, it remained unfinished, as the successor of Urbain probably did not think it proper to continue the work of his predecessor. Such as it is, the church of St. Urbain of Troyes

shows, through the master-builder, who was intrusted with its construction, a singular hardihood and a truly amazing knowledge of building. If the date of the foundation of the church of St. Urbain and that of the interruption of the work were not historical facts of undeniable authenticity one would be tempted to suppose that this edifice was built toward the beginning of the fourteenth century.

We ourselves, despite proofs so incontrovertible, have long hesitated before believing that the thirteenth century had seen begun and finished what there was of this monument; being in the habit of relying first of all upon archæological signs, we could not give to the construction of Saint Urbain a date earlier than the fourteenth century; but a profound study of the structure has shown that historical tradition was in accord with fact. They no longer built thus in the fourteenth century. Only, the architect of St. Urbain was one of those artists in whom the most advanced theoretical principles are allied to a profound experience, to a skill that is never at fault, to a sure knowledge of the quality of the materials, to infinite resources in execution and to natural originality; he was, to put it briefly, a man of genius. His name is unknown to us, like those of most of these laborious artists; if Urbain IV had sent from Italy an architect to build his church at Troyes, certainly we should have known it, but we should not have to spend much time over his work, for Southern Italy at that time was raising only structures that do not furnish types suitable for study.

The plan of the church of St. Urbain of Troyes belongs to Champagne. The choir recalls that of the little church of Rieux, that we have already given; upon the four piers of the crossing there was to be a tower, probably very high, if one examines the broad section of these piers. Two other spires flanked the entrance, accompanied by a porch projecting like that of the church of St. Nicaise, at Rheims. The central tower was not commenced and the nave and façade remained unfinished. From what remains of these parts one can give an exact account of what this church was to be.

The choir and the transepts are complete. Let us cast our eyes first upon the plan of the church of St. Urbain (Fig. 102) taken at the ground-floor; this general view is necessary in order to appreciate the different parts of its structure. This plan presents points of support that are solid, thick and resistant, a very simple general arrangement.

Placed between two streets, two deep and well-protected porches give entrance to the two arms of the transept. Above the ground-floor, at a height of 3.30 metres, the whole building looks like a lantern of glass of extreme lightness and supported by the buttresses, which alone remain solid, as far as the gutters above. Hence it is the construction of these buttresses which must occupy us in the first place.

Figure 103 gives one of the buttresses of the apse parallel to one of the lateral surfaces. The solid basement, 3.30 metres high, ends at *A*. At *B′* is drawn the horizontal section of the pier at the level *B* and at *C′* the horizontal section at the level *C*. *D* is the open-work set with glass outside of the gallery *G*; *F* is the free open-work holding the ceiling *H*, which serves as a passage on the level of the supports of the large upper windows; *E*, the mullions of these glass windows. The archivolts of the windows, whose extremity is at *I*, serve as wall-arches to the great vaults. The gutter, *K*, above is supported on the inside by the filling placed upon the archivolts *I* and on the outside by an arch *L* and a whole system of open-work, whose details we will soon give.

The open-work at *D* and *F* is partly set in grooves, so that these are both independent of the piers and are real sashes of stone, enclosed between the buttresses.

Let us say one word about the materials which enter into this structure, for their quality is partly the cause of the system adopted. Even at Troyes, they could not procure freestone; for the region furnished only chalk, good, at best, only to make the filling for vaults. The architect of St. Urbain had to bring stone from Tonnerre for

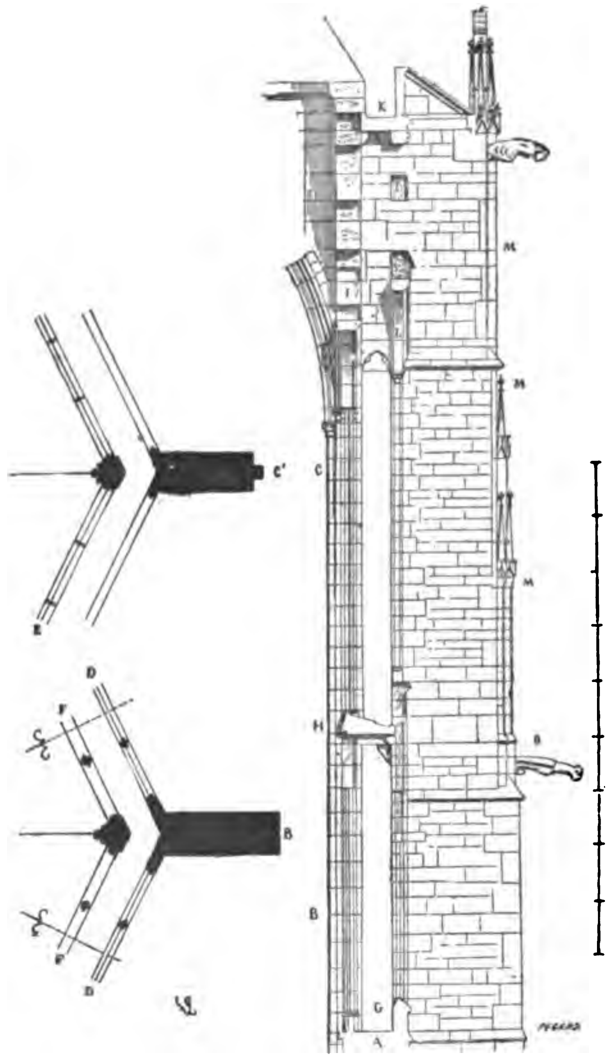


Fig. 103. Buttress of St. Urbain, Troyes.

the facings and in order to economize these materials, transported at great cost, he used, so far as he could, a certain stone called Burgundian, found several leagues from Troyes and proving to be only a coarse limestone, firm enough, but in shallow courses and cutting badly. It is with these latter materials that he built the solid part of the piers, covering their outer surface *M* with great slabs of stone from Tonnerre, set against the cleavage and finely cut. So, also, with the stone of Tonnerre he built the inner piers, the open-work, the arches, the gutters and all the delicate members of the structure; now, the stone of Tonnerre here used is a species not very thick, but of great resistance, firmness and compactness and capable of being set against the cleavage without danger. In fact, this building is a structure of scappled stones, solid but clumsy, finished off with a fine and very beautiful stone, used with the strictest economy, as we would use marble to-day.

The lightness of the open-work and the mullions surpasses all that we know of in this class of work and yet the materials used have been so well chosen and the elasticity of the structure is so complete that very few of the pieces are broken. Moreover, as the structure is perfectly solid and well balanced, the injuries occurring to the open-work and windows have no importance, since the latter can be easily replaced, like real sashes, without affecting the principal structure.

The anatomy of this building must be examined with the greatest care. We shall try to bring out the details vividly before the reader.

First, then, let us take that part of the pier included between *H* and *O* — that is, the ceiling of the gallery and its lintel joining the inner pier to the outer one, the casings of the open-work and the drainage for the water at this point.

At *A* (Fig. 104) we see the section taken through the axis of the outer and inner piers. *B* is the gargoyle throwing off the water collected in the passage *G* — that is to say, not only the rain which falls vertically upon this slab, which is a small matter, but that

which beats against the glass; *C* is the gutter of the roof, acting as bond-stone — that is, extending through the whole thickness of the pier; *D* is the console sustaining the lintel *E*, which serves as gutter-

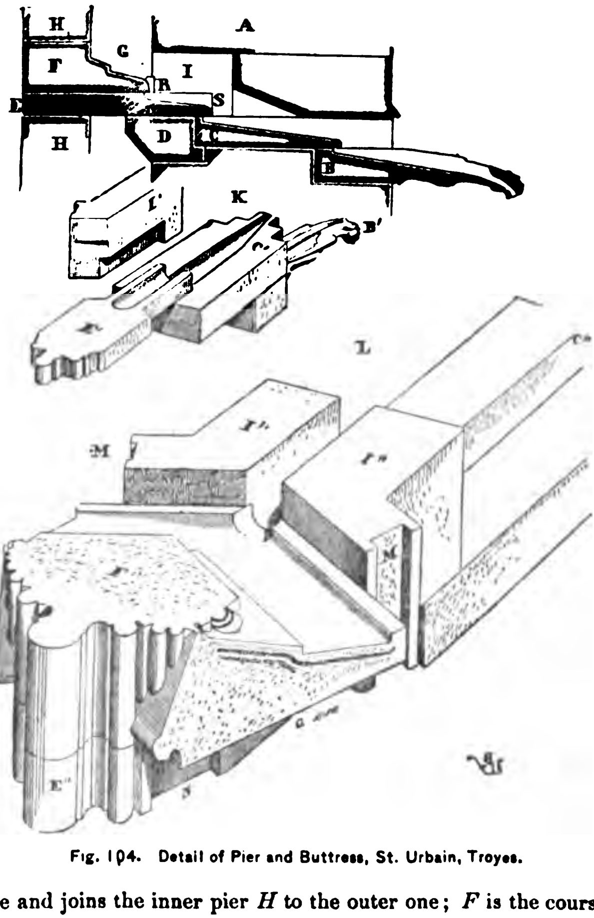


Fig. 104. Detail of Pier and Buttress, St. Urbain, Troyes.

stone and joins the inner pier *H* to the outer one; *F* is the course of the roof of the gallery and supports the gutter; *I*, the two cheeks forming outer facings and holding the lintel gutter *E*, as shown at

I' by the perspective detail K. In this detail the piece E' is the lintel-gutter; C', the second gutter-stone and B' the gargoyle. The large detail L shows, in place, the two pieces I at I'', the gutter C at C'' and the roof piece F at F'' with the lintel E at E''. All this arrangement is made with the greatest care, the stones being well cut and well set; accordingly no rupture is seen.

Let us notice that the gutter-lintel E (detail A) is left free in its course from R to S under the pieces I—that is to say, the bed R S is thick and cemented only after the settling of the structure has produced its effects, so as to avoid all chance of rupture.

We see at M (detail L) the rebates destined to receive the outer glass windows of the gallery and at N those destined to receive the inner open-work supporting the roof-piece and the mullions of the windows.

How can open-work so delicate as in these two windows be kept in vertical planes?

That on the interior is only 21 centimetres thick, and that on the exterior 22 centimetres including all projections. Their rigidity is obtained by the simplest means, in that the arching of each of them, included between the rebates of which we have already spoken, is in one piece. Each section of open-work, then, is composed of but three pieces: two jambs and an upright slab pierced with openings.

We must not forget what has been said previously about the materials used in building the church of St. Urbain. The architect had made his structure of resistance out of common stone, a sort of blocks worked with the pick; and whatever was only accessory, like decoration, gutters, open-work, were of the stone of Tonnerre, shallow and very firm ledges, but of great length and width. These stones of Tonnerre are really only flags, whose thickness varies from 20 centimetres to 30 centimetres and are of excellent quality.

The edifice consists only of piers between which are placed upright slabs with apertures. This singular system of building is

applied everywhere with that rigorous logic which characterizes architecture at the end of the thirteenth century.[1]

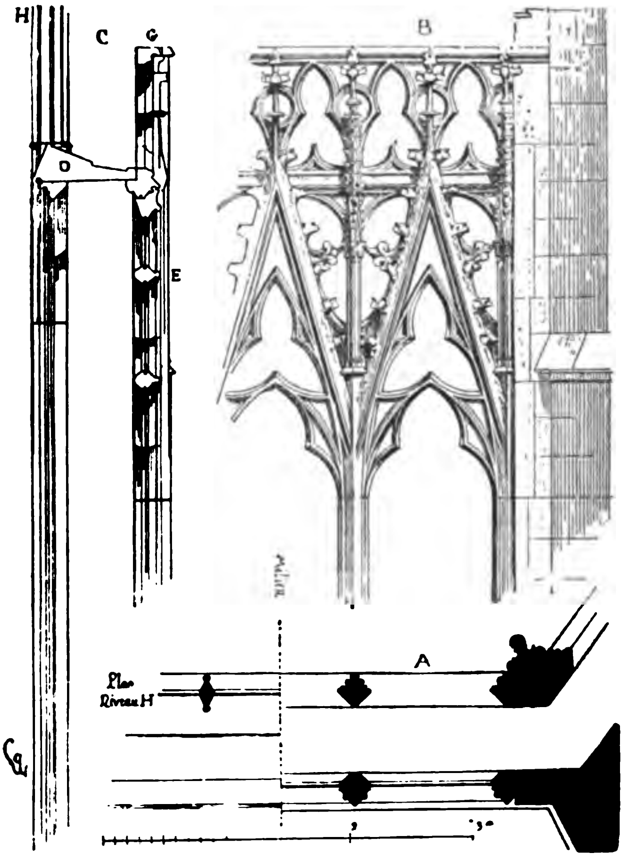


Fig. 105. Outer Open-work of Gallery, St. Urbain, Troyes.

[1] How does it happen that we, who to-day have cast-iron, or can procure stones of excellent quality and in large pieces, have not thought of putting into practice the method so happily applied in the building of the church of St. Urbain? What resources might we not find in the study and the use of this system, so true, so simple and so well adapted to many of our edifices in which are demanded large windows, lightness and swiftness of erection?

Let us take, then, the outer open-work of the gallery in the church of St. Urbain and see how it is cut and kept vertical.

We represent it here in the plan *A* (Fig. 105), in its outer elevation *B* and in its section *C*.

The roofing-stone *D*, making the two sets of arches firm and forming a gutter and a support for the upper windows, is made of one or two pieces joined to the pieces under the inner pillars outlined in *F*′, in the detail of Figure 104.

To give more weight and more rigidity to the great slab, which is cut out so as to form the exterior arching set with glass (Fig. 105), whose section is drawn at *E*, this slab has a railing *G* joined to it and made of the same piece, so that the gutter *D*, forming the ceiling of the gallery. rests upon a projection reserved on the interior along the outer arching, while the lower bed of this ceiling is made fast to the inner arching, also composed of a large slab set upon end, with windows cut through and held at its extremities by the rebates *N*, of our detail *L*, in Figure 104.

We ought to say that to produce a more pleasing effect, the architect has given the interior arched open-work a more delicate design and a different form from that of the exterior arching; and these two openings produce the most brilliant pattern and wonderful effects resulting from the insertion of stained-glass.[1]

Let us now look at the upper part of the structure of the choir of

[1] The decoration which encloses the chancel of St. Urbain was probably not admired by everybody at Troyes; for, some years ago they had the idea of concealing it by an enormous decoration of pine wood and stucco, painted white. Nothing is more ridiculous than that scaffolding of stucco, which displays its pretentious wretchedness in front of one of the most charming conceptions of the art of the thirteenth century in its decline. The barbarism that destroys is certainly more dangerous than the barbarism of the authors of the high altar of St. Urbain; but, still, what would the friends of the arts in Europe say if they saw a façade moulded in plaster erected in front of the western façade of the court of the Louvre, under pretext of embellishment? How much progress we have still to make in order not to merit the title of barbarian, which we give so freely to periods when certainly no one would have been permitted to hide a work executed with intelligence, care and talent behind a useless overgrowth, coarse in material and workmanship, without form and without taste, a product of ignorance combined with the most ridiculous vanity.

St. Urbain, for there the architect has displayed a remarkable sagacity.

If we refer to Figure 103, we shall notice that the upper windows are set in a vertical line with the coping of the roof at *I*, that their archivolts serve both as wall-arches and as relieving-arches for carrying the trusses and that the gutter *K* rests partly upon a projection reserved above this archivolt and partly upon a piece of open-work *L*, fixed about 50 centimetres in front of the window.

Figure 106 gives at *A* the outer surface of this open-work and at *B* the section made through *C D E F*. In this section, we find at *G*, the section of the window, at *H*, its archivolt-wall-arch and at *I*, the vault.

The open-work supporting the gutter *K* consists of an arch reinforced by a gable, performing the duty of a tie.

The open circles *L* help to sustain the gutter along its extent from *E* to *M*. This gutter, in each compartment, is made only of two pieces of stone, joined at the apex of the slopes at *N*; and each of these pieces is cut as indicated in *O*, its junction with the open-work taking place from *E'* to *M'* and the part *P* being cut out and having no drip-stone, in order to let the summit of the gable go through.

The pattern of the gable and the circular openings *L* are faithfully drawn upon our figure. The finial (its shaft penetrating the balustrade) and the point of the gable are made of a single piece of stone, so as to add the necessary weight to the extremity of the pattern. But to avoid all chance of the gable being thrown down outward, the two pieces of the balustrade *R* are not placed in a straight line, but form an angle slightly obtuse, as shown in the plan *S*; *T* being the shaft of the finial at the top of the gable and *R' R'* being the two parts of the balustrade cut each from a single slab.

Hence the apex *T* of the gable cannot be thrown outward, supported as it is by the two open-work slabs *R' R'*, which rest on the tops of the piers pierced by gargoyles to drain off the water, as seen in *V*.

This is rather an arrangement of carpentry than a structure of masonry; but we must not forget that the quality of stone used at St. Urbain lends itself to such a structure and that, thanks to these artifices, the architect has been able to raise a structure of extraordinary lightness, which consists, in reality, only of a masonry of rough stone and upright slabs, pierced with openings.

The flying-buttresses which support the great vaults of this church above the chapels are built in conformity with this system of open-work and of large pieces of stone set like props [see "*Arc-Boutant,*" Fig. 66].

The architect of the church of St. Urbain (his scheme being accepted) has been faithful to his principle in all the parts of his construction. He has understood that in a church so light, built with stones and slabs, it was necessary to allow this open-work great freedom in order to avoid ruptures; wherefore, he has fitted these slabs only into grooves that permit the masonry to settle, without breaking the delicate tracery which constitutes the walls.

We see by examining Figure 106 that the gutters are free, almost like pipes and that, even in case of a break, the dripping of the water could cause no injury to the masonry, since these gutters are suspended over vacant spaces without, by means of these open gables.

It was necessary to be bold to conceive a structure of this kind; it was necessary to be skilful and careful in execution, to calculate and forsee everything and to leave nothing to chance; so, this structure, despite its excessive lightness and despite neglect and unintelligent repairs, is still solid after six hundred and odd years of existence.

The architect required from the quarries of Tonnerre only slabs 30 centimetres thick at the utmost, of great dimensions, it is true, but of comparatively light weight; he thus avoided the greatest expense at that period — that of transportation. As to the handiwork, it is considerable; but in those days this did not cost the most.

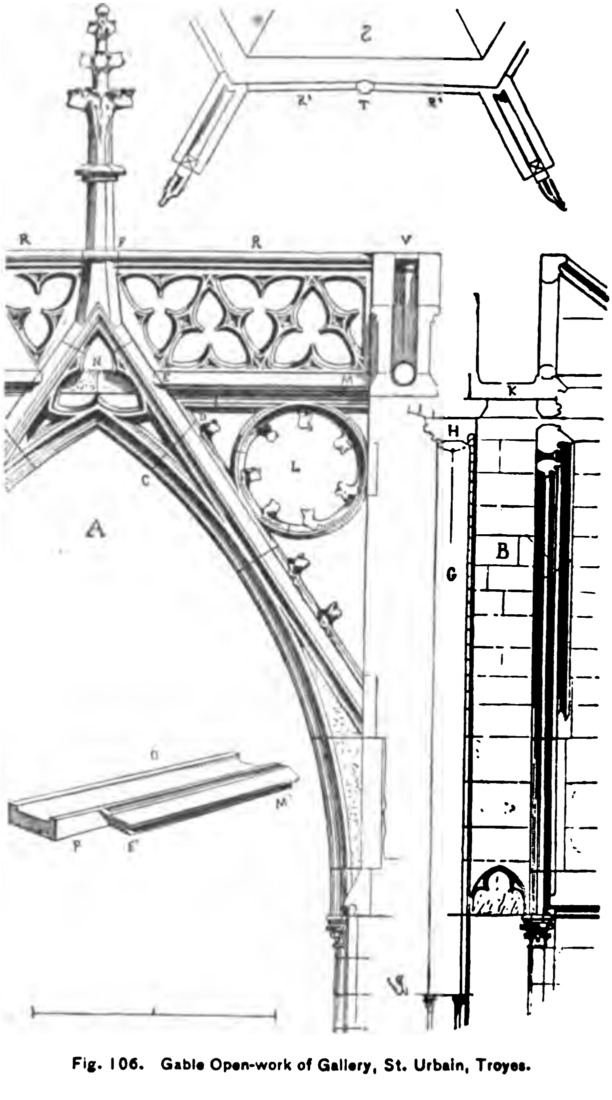


Fig. 106. Gable Open-work of Gallery, St. Urbain, Troyes.

The church of St. Urbain will often appear in the course of this work, for it is certainly the utmost limit to which building in stone can attain and as an architectural composition it is a masterpiece [see "*Arc-Boutant,*" "*Balustrade,*" "*Croix,*" "*Fenêtre,*" "*Gargouille,*" "*Porche,*" "*Porte,*" "*Vitraux*"].

We must now retrace our steps somewhat. In Ile-de-France, as we have already observed, we could not point out the boldness of the Burgundians at the beginning of the thirteenth century, or that of the architects of Champagne at the end of that century, when these latter could use large materials, hard, close-grained and resistant, like the stone of Tonnerre.

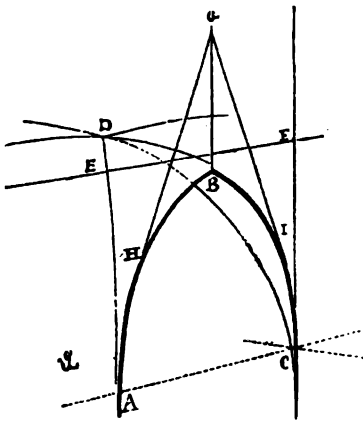


Fig. 107.

The builders of Ile-de-France make scarcely any of that open-work, formed of a single stone, those partitions pierced with openings: they keep the stability of their edifices less by rigid surfaces and supports than by weights accumulated at the points which seem to them to present an insufficient base.

We find a remarkable proof of this fact, from the middle of the thirteenth century, in the great constructions.

We have seen that the Gothic architects had arrived, in vaulted edifices, at considering the wall-arches as relieving-arches and at taking out the structure under these wall-arches, so as to keep only buttresses. They did away with the walls as being a useless accumulation of material between these buttresses, since the latter had to receive and support all the weights; but these wall-arches, not being weighted at the key, might deviate from the perpendicular,

because of the pressure and the thrust of the rows of filling stones in the vaults which they supported.

Let us remark (Fig. 107) that the wall-arch *A B C* at the apex of its two branches, at the key *B*, where this pointed arch shows the greatest flexibility, receives the very last rows of stones in the filling *B D*, which have a slight thrust from *D* to *B*, because of their curvature.

It might happen that the apex *B* would be thrust out of the vertical, if not made immovable. To build a wall upon this arch *A B C* could strengthen the arch very little, since the two triangles of masonry *A E B* and *C F B* press far more upon the haunches of this arch than its key *B*. The surest plan was to load the key *B*. Hence the builders arrived, by the middle of the thirteenth century, at building outside, upon the wall-arches of the vaults, gables *H I G*, of masonry, framing the apertures and thus rendering, by this additional weight *B G*, the summits of the wall-arches immovable, or at least stable enough to resist the thrust from the keys of the vault-fillings *B D*.

One of the first attempts of this kind is seen in the Sainte-Chapelle-du-Palais, at Paris.

Let us observe that the architects of Champagne, who had adopted wall-arches of strong resistance because of their great thickness, since they were real pointed cradle-vaults, to receive the fillings of the vaults; and that the Burgundian architects, who detached their wall-arches from the outer partitions, leaving between them and these partitions a rather broad space supported by the courses of the crowning piece, had no need to resort to the artifice explained in Figure 107.

It was only in Ile-de-France, Beauvoisis and Picardy that we see, toward 1240, the adoption of this means of giving stability to the wall-arches. Thus the differences in the character of the architecture of the various provinces of France, in the thirteenth century, are nearly always to be explained by a necessity of building. If

any one wishes to learn about the usefulness of these gables, regarded generally as ornaments, he must examine Figure 108.

But architecture is an imperious art. As soon as you modify one e/

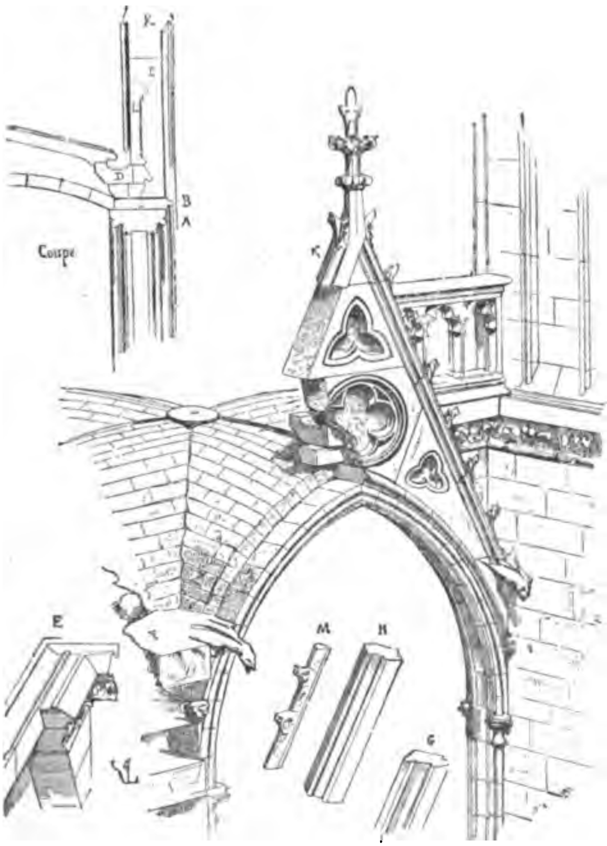


Fig. 108.

of its members, as soon as you add anything to the arrangement, you see the difficulties of detail accumulating. A first change in the system, which you suppose trivial at first, demands a second, then a

third, then a crowd of others. Hence you must either go backwards, or become the slave of necessities which you have evoked by a first attempt, or a first concession.

One struggles against these successive difficulties which seem to arise in proportion as he overcomes them. In days when idleness of mind is regarded as a virtue, men treat these perilous attempts as vicious tendencies, as forgetfulness of sound doctrine. But the architects of the Middle Ages and especially of that period which now occupies us, would never have thought that a step backward or a repentance was progress; they felt that they were led by their own principles and they solved courageously each of the new difficulties which they were continually raising.

To surmount the wall-arches with triangles of stone, in order to weight their keys, means at first only a little more stone and a little more handwork. But there must be gutters upon the wall-arches, and balustrades above the gutters; these gutters must rest upon the arches and not upon the filling of the vaults; the slopes of the gables must themselves throw off the water in some way; these rigid lines must be embellished; and this new member added to the architecture must find a place without intruding upon that of other indispensable members.

Figure 108 explains how the builders at the middle of the thirteenth century were able to reconcile at once both the purely material requirements and those of Art.

They set over their wall-arch *A* (see the section), often strengthened and doubled by an archivolt *B*, having the thickness of the filling-stones of the vault, about two-thirds of the width of these arches, the solid gable *C*, leaving a shallow notch at its base in order to fit in the gutter *D*, set over the remaining third part of the width of the arch. The gable being detached, this gutter had a dripstone overlapping the cornice, as seen in *E* and received the balustrade, as usual, in a groove.

Two stones *F*, carrying a basin and gargoyles, were placed at

the base of the gable to collect the water falling upon the roof-pieces of these gables. These roof-pieces, made in long sections to avoid joints, were cut according to the outline *G* and beneath the cornice were imbedded in the tympanum and were provided, behind the crockets, set in grooves, with a little furrow *I*, suitable for collecting the water and guiding it to the basins of the gargoyles.

Above the cornice these roof-pieces were then cut according to the drawing *H*, throwing off the water in front and behind. A head-piece *K*, made in one piece of stone, maintained the extremities of the two inclined roof-pieces, as also the branches of crockets. The balustrade *L* was set behind, level with the rear surface of the gable, in order to make way for the rows of crockets *M* inlaid in the grooves. Later they completely hollowed out these gables, which appeared too heavy to the eye, above such light mullions in the windows. This example shows how each new member added to the Gothic architecture led to a series of details, studies and combinations.

Some one will perhaps tell us that the efforts here are too great for the causes that evoke them; the criticism will be just, but it is too general. In the natural order of things how many complicated arrangements do we not see, how many details, how many long and powerful efforts to produce apparently trifling results? It is not we who created the world, who presided over its ordering and if things are well arranged in it, we must yet grant that this arrangement is far from simple.

The architects of the Middle Ages will admit a criticism that might be addressed to the great Orderer of the Universe. These architects, like their predecessors, had inert matter to work upon; they had to submit to the laws of attraction and resistance and to take account of the wind and rain. In the presence of inert matter and the action of natural forces, they believed that equilibrium was the true law of construction. Perhaps they deceived themselves; but it will at least be admitted that they deceived themselves like men of genius and there is always some good to be gained from men

of genius, even when they are deceived. Moreover, it must be conceded that the more man seeks the more he combines and complicates matters and the sooner he ascertains the weakness of his judgment. Here are *rationalists* (if I may use the term), artists who follow a principle, ready to accept anything in conformity with the strictest rules of logic; who take, for building, fine stone, that is to say, a substance shaped in such a way as to be set in courses; hence the principal lines in their construction must be horizontal. But no; after half a century of attempts of combinations, each more ingenious than the preceding, they come, on the contrary, to making the vertical line predominate, in their edifices, over the horizontal and that too without ceasing for an instant to follow the consequences of the true principle, which they have laid down. Many causes conduce to that result. We have mentioned some, as, for instance, the utility of stones set upright to make buildings rigid, or the necessity of weighting the points of support liable to be forced out of their vertical by oblique thrusts. There is a last point which has its importance: in the cities of the Middle Ages space was limited. Every city, because of the feudal system, was fortified and they could not move the fortifications of a city every ten years; hence it was necessary to enclose the monuments in narrow spaces and to take up as little room as possible

Now, if you build by a principle which makes all the actions of your structure oblique and if you cannot take more space, you must make up by vertical weights for the room which you lack on the surface.

A law originally imposed by necessity and endured as such, soon becomes a habit and a need; so much so that even when one could get rid of it, he submits to it, it becomes pleasant and enters into his customs.

From the time that the architects of the Middle Ages learned that the structure of their vaulted buildings required them to multiply the vertical weights so as to resist all oblique pressure, they

freely accepted the situation and, as in an edifice, either the horizontal line must necessarily prevail over the vertical, or the latter over the horizontal, unless they wished to have a real checker-board pattern, they ended by suppressing the horizontal line almost entirely, keeping it only to indicate the level of the stories, to show a resting-place within, or a floor. Also, carrying their principles always farther and farther, the master-workmen, at the end of the thirteenth century, show clearly, on the outside of their edifices, the interior arrangement and in this we should do well to imitate them. If we examine the outside of a Gothic building we can say whether it is vaulted in stone or roofed with timbers.[1]

Its pinnacles indicate to us the number of its interior supports; its bands, the levelling-stones above the vaults; the strength of its buttresses, the force of the thrusts and their direction; its windows, the number of wall-arches and compartments; the shape of the roof, the perimeter of the various halls, etc.

At St. Urbain of Troyes, already, the different members of the structure are so delicate and they have each a function so clear and independent, that the architect assembles them, but does not bind them together. He places them one beside another, keeps them together by mortising and fitting them in, as in joining; but he avoids binding them, for this produces homogeneity of all the parts and this the builder fears in using a system where every part of the structure acts, resists, — has its own action and resistance, — an action and resistance which can be effective only so far as they are independent.

At the beginning of the fourteenth century this system of allowing to each member in French construction its own function and of

[1] In this regard and to show how far opinions upon architecture are false to-day, we shall here quote the opinion of a man, otherwise very enlightened, who, seeing the outer buttresses indicated in a plan, wished to have the architect suppress them, for the reason that the *progress* of construction ought to do away with these appendages, applied to buildings in barbaric ages and showing nothing but ignorance, etc. One might as well say that we are too civilized to be truthful and that falsehood is the most certain mark of progress.

uniting these members in accordance with the individual function of each, is carried to exaggeration. This is very evident in a highly interesting monument, built from 1320 to 1330; we refer to the choir of the church of St. Nazaire at Carcassonne, one of the rare original conceptions of a period during which the art of architecture had already fallen into the use of formulas and cast aside every new attempt, every individual expression.

The careful examination and analysis of this monument have revealed a fact interesting to us to-day: it is the simple method followed by the architect and his subordinates for building a structure seemingly very intricate and apparently requiring a fabulous number of operations and drawings. In reality the difficulties of arrangement do not exist. This structure is merely a collection of vertical planes, whose horizontal projections need only a simple drawing each. It must be admitted and well understood, first of all, that the architect knows what he wants, — that he actually *sees* his building, under all its aspects, before laying the foundations; that he has looked out for all the different parts of his construction; that he has done, before cutting the first stone, all the work that we do upon an edifice when measuring and studying its final details.

Gothic architecture is exacting upon this point and perhaps this is what brings it most of its enemies. It is so consoling to say, when a difficulty meets us on the spot, "We shall see about that when we come to the plastering." It is so painful, when everything is not provided for in advance, to listen every day to a long series of questions from the stone-cutter or the overseer, — questions which must be answered clearly and simply, as by a man who knows what he is going to do and has foreseen everything that can possibly be required!

Accordingly the architect of the choir of St. Nazaire at Carcassonne made not only the plan of his edifice, not only the elevations and cross-sections, but he knew beforehand the exact point where the various arches spring, meet and intersect; he drew their profiles and knew exactly upon what they were to rest; he knew the results

of the thrusts, their direction and their force; he estimated the weights and reduced the pressures and the resistances to their most exact limits. He knew all this beforehand and he must have known it from the time when the first course was placed above ground.

His conception being thus complete, fixed on paper and in his brain, his subordinates go blindly forward. He says to one: "Here is

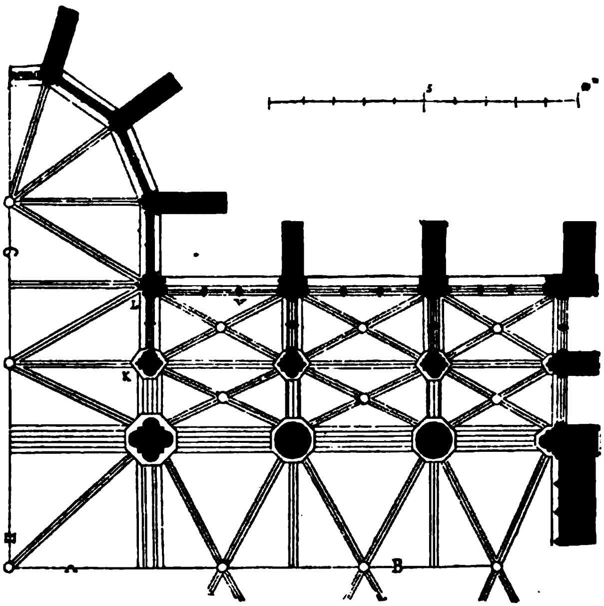


Fig. 109. Choir and Transept of St. Nazaire, Carcassonne.

the design of the pier *A*, repeated twice; this is the design of the buttress *C*, repeated ten times, etc.; here is the drawing of the window *A*, repeated six times and of the window *B*, repeated seven times; here is a branch of a diagonal arch with its stones of impost, of a transverse arch with its imposts, etc." This being said, the architect can go away and let all the courses and the parts of each member be cut out. The cutting finished, a master-setter comes,

who, without possible mistake, has all these different pieces taken up and put into their places, like the pieces of a well-planned machine. This mode of procedure explained how, at this period (at the end of the thirteenth century and during the fourteenth century), French architects had monuments erected in countries where, perhaps, they had never set foot; how from Spain, from the south of Françe, from Hungary and from Bohemia, requests came for designs of monuments by these architects; and how these monuments could be built and exactly resemble, save in some details of profile and sculpture, the edifices built between the Somme and the Loire.

The choir of the church of St. Nazaire at Carcassonne was probably erected thus, with the aid of plans furnished by an architect of the north, who perhaps scarcely visited the city.

Our reason for this opinion is that, evidently, the architect has avoided every difficulty requiring a decision on the spot; those difficulties which one solves, not by a design, but by explanations given to the stone-cutters and workmen in the very work-yard while watching their work and taking, if necessary, the gauge, the rule, or the square and applying it to the design. The architect, for instance, has almost entirely, in the vaults of this edifice, given up imposts common to several arches; he has given the curve of each of these arches and their profiles; each has been cut without regard to the adjoining arch and the master-setter has arranged all this like a game of patience. But in order that the singular method of construction used in the choir of the church of St. Nazaire at Carcassonne may be appreciated, it is best to give, first, half of the plan of this choir with its transept (Fig. 109).

We see in this plan the horizontal projection of the vaults; they have all their keys on the same level, or nearly so, although their dimensions and forms are not alike; so, necessarily, the springings of these arches are found on very different levels.

We must also see the general section of this building through *A B*. The architect had thought of closing the vaults *C* (Fig. 110) at a

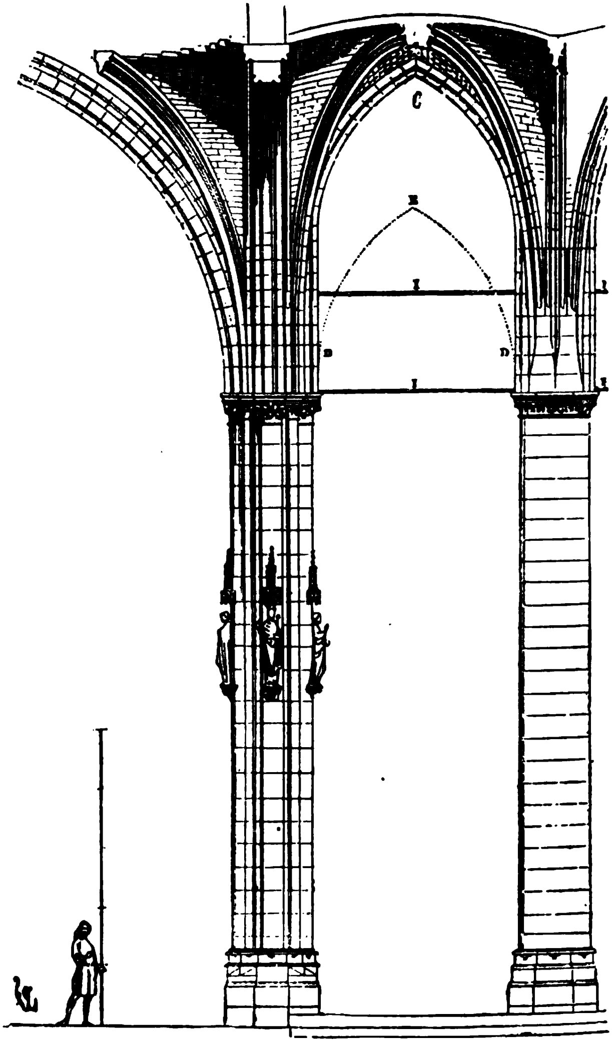


Fig. 110. Transept Arch, St. Nazaire, Carcassonne.

level below that of the great vaults of the chancel and of the transept; and the structure had been so built up above the springing of these low vaults, as seen by the dotted lines *D E*.

But the architect had to yield to the desire for greater effect, by raising the keys of all the vaults to the same level. Perhaps a requirement from the clergy caused the adoption of this latter course; but certain it is that the low starting-points, indicated by dots, were cut off at the surface of the piers, as can be easily seen and that these springings were raised, as indicated in our drawing, in order to have through the whole extent of the edifice windows of equal height.

Figure 111 gives a section through the line *G H* of the plan.

Let us at once notice, that, to hinder the buckling of these slender piers, subjected to the unequal thrusts produced by the elevation of the secondary vaults, the architect has fixed bars of iron, *I*, 0.05 centimetres square, to be seen in our two sections and that the stone used is a hard and resistant limestone, which permitted them to place the vaults upon these slender supports.

Let us now examine with care the details of this structure; let us take the summit of the pier *K* (of the plan) at the point where that pier receives a large intermediate transverse arch of the chancel, two archivolts, a transverse arch of the chapel and two branches of diagonal arches.

The horizontal section of this pier (Fig. 112) is drawn at *A*.

From *B* to *C* we see four courses of stones to receive the large transverse arch.

Starting from the section *C*, normal to the curve of the transverse arch *E*, the voussoirs of that arch are independent and the pier rises behind the filling *F* of that arch, without being attached to it, up to the capital of the wall-arch *G*. The projection of this capital forms a connection with the filling and then the pier rises, again independent, up to its meeting with the wall-arch *H*.

Above the capital, *G*, the filling rises vertically from *I* to *K*. It

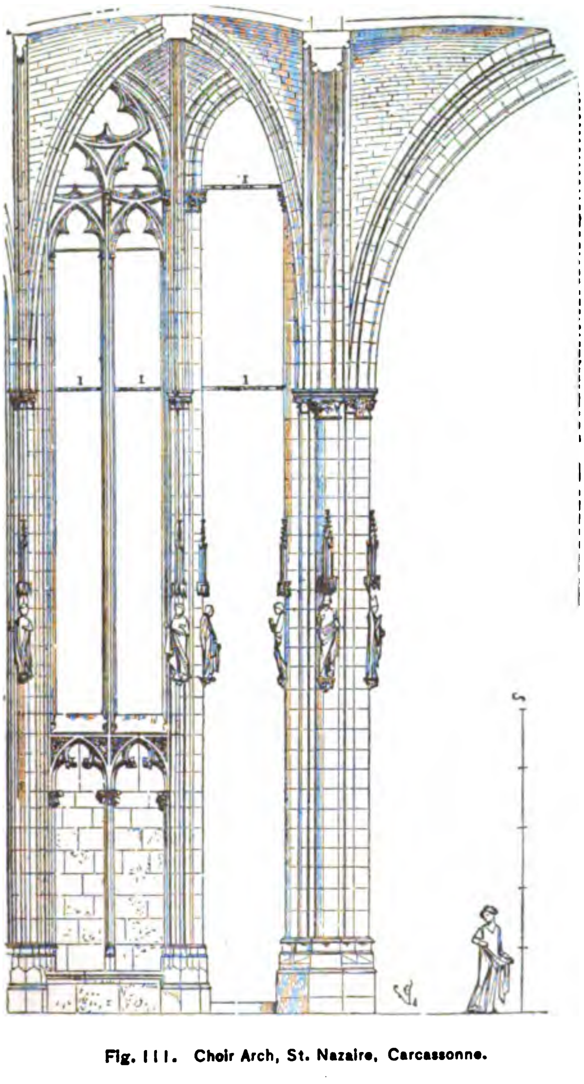


Fig. 111. Choir Arch, St. Nazaire, Carcassonne.

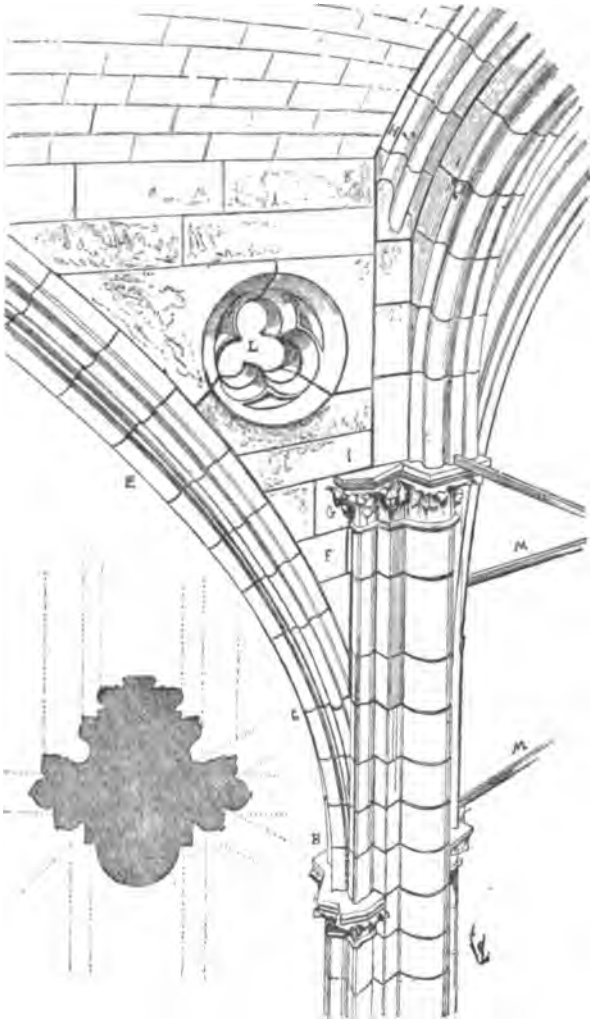


Fig. 112. Choir Pier, St. Nazaire, Carcassonne.

is pierced by a trefoil, *L*, which ornaments the bareness of this triangle, receiving the vaultings of cut-stones.

The two bars of iron *M* serve as ties between this pier and the one adjoining and maintain the thrust of the transverse arch *E*.

Let us take the adjoining pier *L* of the plan, that of the entering angle, which is located between three windows and which receives a large transverse arch, two branches of the great diagonal arches of the principal vaults and a third branch of a diagonal arch from the chapel (Fig. 113). It is again seen that here the drawing of each part has been made independently of the rest and that the arrangement shows only the fewest possible connections, in order to avoid too complicated designs. This independence of the different members of the vaults, in falling upon the piers, allows great elasticity to the structure, — an elasticity necessary in a monument so light, very high and very unevenly weighted. It can, in fact, be affirmed, that in the choir of the church of St. Nazaire there have been torsions and considerable movements, without in this way destroying any of the solidity of the building.

Once more, these are not examples to follow, but useful ones to know, because of the simple and practical means put in operation.

In Figure 114 we see the outer side of the same pier. We are placed in the angle of the chapel, at the point *V* of the plan; we suppose the upper mullions of the great window of this chapel to be taken away.[1]

At *A* is seen the bar of iron which maintains the tops of the pillars of these mullions and which serves at the same time as a tie for the springing of these arches [see "*Meneau*"]; at *B*, the groove reserved for setting the open-work centering of the mullions; at *C*, the stones of impost of the wall-arch that encloses the window-frame of cut-stone; at *E*, the branch of the diagonal arch of the chapel-vault, whose courses of impost are mingled with those of the wall-arch.

[1] This operation having taken place under our eyes, we have been able to ascertain very exactly and here reproduce that construction.

Starting from the bed *D*, the voussoirs of that diagonal arch are independent.

At *G* is the archivolt surrounding the carved open-work centering of the first window in the chancel and filling the place of

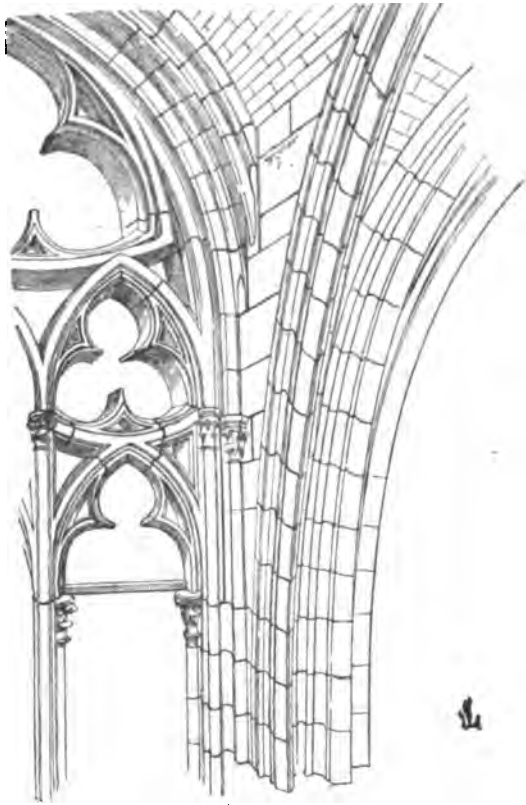


Fig. 113. Choir and Chapel Pier, St. Nazaire, Carcassone.

wall-arch of the interior, at *F* the archivolt wall-arch of the mullions without glass, separating the chapel from the choir. Here it will be observed that this arch *F* is moulded even in the part hidden

by the masonry of the entering angle behind the diagonal arch *E*, which proves in the clearest manner that each member of the structure was separately outlined and cut in the work-yard after detail designs and that these different parts thus prepared by the stonecutter were put into place by the setter, who alone knew each of their functions and their relations with the whole of the structure.

The mason filled the gaps remaining between these interlacing, interpenetrating members, all remaining free.

We have drawn at *K* the horizontal projection of that entering angle, with the intersection of the two archivolt-wall-arches *G*.

Such a structure consists only of piers holding elastic but resistant groins, supporting the fillings of the vaults, or maintaining the sashes of stone in the large grooves.

It shows us that the master-builder could leave nothing to chance, postpone nothing; that he could foresee everything from the first course, classify his designs methodically and that he needed, when once the stone was cut according to the designs and the pieces ready, only to give instructions to a skilful stone-layer, who took successively all the parts of the structure and put them in order into their places, as the master-carpenter takes, one by one, the pieces of timber, cut in advance, in order to raise them to their places.

To-day people proceed otherwise: they collect the blocks of stone, often without knowing very definitely what form they will finally take and they cut in these same blocks the intersections of the voussoirs and the mouldings, as one might do in a homogeneous mass, without very much anxiety about the beds and joints that fail to coincide with the given forms. Is this better? Is this the means of obtaining a more solid structure? We beg leave to doubt. We can affirm, on the contrary, that it is less reasonable, less skilful, less intelligent and more costly.

There is no religious construction of the Middle Ages more advanced than that of the churches of St. Urbain of Troyes and St. Nazaire of Carcassonne, in the path opened by the architects of

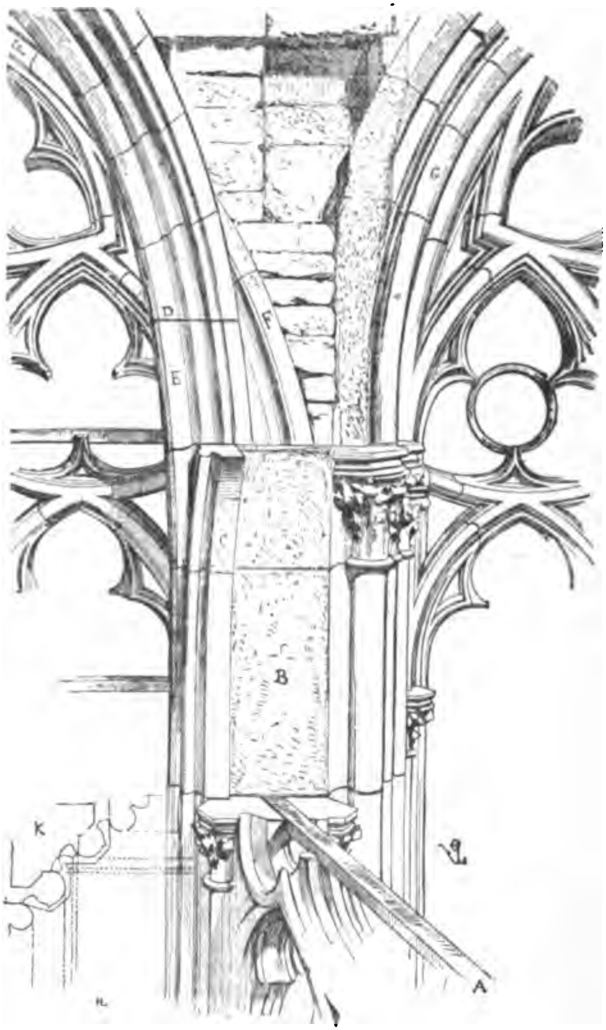


Fig. 114.

the thirteenth century. They could not, in truth, go farther without substituting metal for stone.

It is doubtful whether the architects of the fourteenth century were checked by that impossibility, or whether their fruitless efforts had proved to them that they had already passed the limits imposed by matter: in any case a reaction took place about 1330 and the builders abandoned these too-bold methods to return to a wiser system. But this reaction ended by destroying originality; they came to formulas. At that period we see the builders casting aside, in the vital parts of their structures, that simultaneous use of stones set upon their bed and against the stratum, which had furnished the builders of the thirteenth century with such beautiful subjects for decoration. They keep the forms prescribed by this system, but no longer appreciate the reason for them and, losing something of the adventurous spirit of their predecessors, they give up the stones set against the stratum as a means of rigidity for the supports and return to structures built in courses, reserving the stones set against the stratum for mullions and inlaid arching,— that is, for the architectural members supporting no weight and serving only as window-sashes or decorations. Still, as if to follow, in appearance at least, the consequences of the system devised during the thirteenth century, they multiply the vertical lines and wish that not only the members of the vaults, the arches, shall have each its point of support, but even the mouldings with which these arches are ornamented. Hence there results between the form given to the piers, for instance and the construction of these piers, the most evident contradiction. In fact, the builders of the fourteenth century return to heavier forms, although they try to disguise that reaction under an apparent lightness, by multiplying the slender members of the architecture. As workmen they are very clever, very prudent, experienced and skilful, but they entirely lack invention. They have no more of that boldness which indicates genius. They are wiser than their predecessors of the thirteenth century, but they

have the defects which often accompany wisdom; their sure methods, their formulas, are stamped, despite all their efforts, with a wearisome monotony.

One of the most striking and most complete examples of religious construction in the fourteenth century is the Cathedral of Narbonne, whose choir only was built from 1370 to 1400.[1]

It is the work of a consummate master of the art, though lacking in that imagination, those unexpected resources which charm us in the constructions of the thirteenth century and which lend themselves to the most varied conceptions.

What gives the architects of the fourteenth century this degree of practical skill was that repairing of the lower structures, those partial reconstructions made in the older edifices. At this period the materials used are always of the first quality, the design learned, the arrangement excellent and the cutting executed with remarkable care. Otherwise the general system of construction is modified very little, but is applied with more sureness and with perfect knowledge of active and passive forces, of thrusts and weights. The flying-buttresses, for example, are well drawn and set just where they ought to be. We have a very clear proof of this in the Cathedral of Paris. All the flying-buttresses of the nave and of the choir were rebuilt at this period (toward 1330), and rebuilt so as to clear the galleries above the aisle and fall upon the large outer piers [see "*Arc-Boutant*," Fig. 59, "*Cathédrale*"].

These flying-buttresses, which have a very long radius and hence a curve very slightly marked, have been calculated with an exact knowledge of the function they had to fulfil and when we reflect that they had to be rebuilt under new conditions and resting upon old structures, we are obliged to recognize in these builders of the fourteenth century a great experience and an uncommon skill.

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[1] It should be said that in France we have not a single large edifice complete, in the architecture of the fourteenth century. The thirteenth had left no great monuments of this class to be built and the fourteenth could only finish edifices already begun, while they had no leisure to finish the small number founded by themselves.

We do not believe that we need continue longer upon the religious constructions of the Middle Ages, for we shall teach our readers nothing new, after what we have already said.

The articles in the "*Dictionnaire*" state elsewhere the differences resulting from the improvements in detail, added by the architects of the fourteenth and fifteenth centuries, in religious constructions.

We shall now devote ourselves to the civil and military constructions, which proceed after their special methods and have but little relation to the construction of edifices purely religious.

CHAPTER IX.

Civil Construction.

IN the early part of the Middle Ages the Roman traditions had perpetuated themselves on Gallic soil in civil as well as in military constructions; nevertheless, wood played a more important rôle than during the Gallo-Roman period. The Gallo-Roman system of construction does not differ from the Roman system; the same methods are employed, but more coarsely, so far as the execution is concerned. During the Merovingian period one meets with very frequent employment of wood, not only for roofs, but in ceilings, wainscots, porches, even the walls of dwellings. Germany and the Gauls produced timber in profusion and this material being easily employed it was natural to use it in preference to stone or brick which take time and require difficult quarrying, dressing, laborious transportation or previous burning.[1]

The conflagrations which destroyed so many towns and villages

[1] It is only toward the end of the thirteenth century that the forests of the Gauls began to diminish in extent and in quality, that is to say from the moment when the feudal organization began to grow weak. During the fourteenth century many feudal lords were obliged to dispose of part of their property and the monastic establishments, the chapter-houses or the parishes cut down a notable portion of the forests of which they had become possessors. Subsequent to the wars of the fourteenth and fifteenth centuries, the forests in many localities, no longer being under the beneficial administration of the feudal system, were cruelly devastated. Those which existed on the mountains were thus lost forever in consequence of the washing-away of the soil from the steep slopes. It is thus that the south and all the centre of France at present are despoiled of the forests which once garnished the plateaus, whose existence is still noted up to the end of the thirteenth century.

during the ninth, tenth and eleventh centuries helped to bring about the abandonment of wood in the construction of private dwellings as well as of churches. This material was no longer employed except for flooring, roofing and the partitions of dwellings. Already in the twelfth century, a number of towns showed façades of houses in dressed-stone or in rubble-work — leaving out of account certain regions deprived of quarries, like Champagne and Picardy, for example.

The monastic establishments, so wealthy in the twelfth century, set the example of civil constructions in stone and this example was followed by private individuals. It must be said to the honor of the builders of this epoch that in adopting ashlar or rubble in place of wood, they very frankly took a mode of construction suitable for these materials and did not attempt while using them to reproduce forms or arrangements which were suitable for timber construction.

Always disposed to preserve its real function and the appearance befitting it, for the material employed, they did not attempt in the least to dissimulate the nature of the materials. The means employed were, nevertheless, of an extreme simplicity and those artists who in their ecclesiastical constructions from the twelfth century onwards showed a singular subtilty, research and used such complicated methods, contented themselves in civil buildings with the most natural and the least complicated. Economical of materials, which then cost comparatively more than to-day, their dwellings are during the twelfth and thirteenth centuries reduced to what is strictly necessary, without pretending to appear anything more or different from what they really are, that is to say, walls, pierced with openings, carrying floors formed of exposed beams and joists, well sheltered on the street and court-yard fronts by projecting roofs, throwing the water well away from the faces. Very rarely, unless it may be in a few towns of the south and centre, the ground-floors were vaulted, consequently there were no buttresses, no projections on the exterior. Most frequently the walls are in exposed scappled rubble-work with

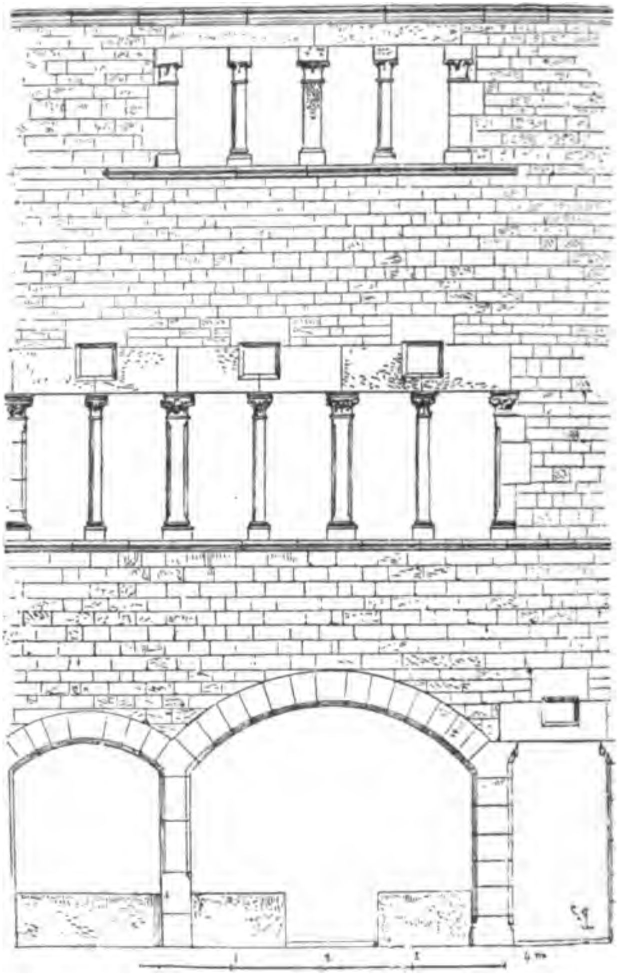

Fig. 115. A House at Cluny.

the occasional belt-courses, the jambs and the lintels of doors and windows of cut-stone; still these lintels and these jambs are not

bonded but are simply facings on the outside; — the belt-courses alone bond together the interior and exterior surfaces of the walls.

In order to give an idea of the commonest sort of civil constructions of the twelfth and of the beginning of the thirteenth centuries and of the simplicity of the means employed, we shall choose from a great number of examples one of the houses of the town of Cluny, so rich in Mediæval dwellings. Figure 115 shows the face of the exterior wall of this house on the street side. It is simply a rubble construction with a few cut stones for the belt-courses, the arches, the windows and their lintels. The first row arches open into the shops. At the right is the door to the alley which leads to the staircase. The second story shows an open gallery composed of uprights

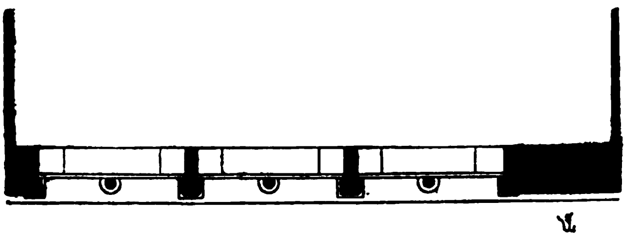

Fig. 116.

and colonnettes lighting the large room. The window openings are square so as to receive movable sashes. In the lintels underneath the arches carrying the third-story wall are pierced small windows with sashes. The third story is lighted by a less important opening and strongly projecting roofs throw the water away from the outside walls.

In plan the second story gives Figure 116, and Figure 117 reproduces the front wall seen from the inside with its relieving arches above the lintels of the second story, the seats in the windows and the supports of the girders sustaining the joists. These principal girders placed along the front wall between the arches bond together the two parallel walls of the house and act as anchors. These were

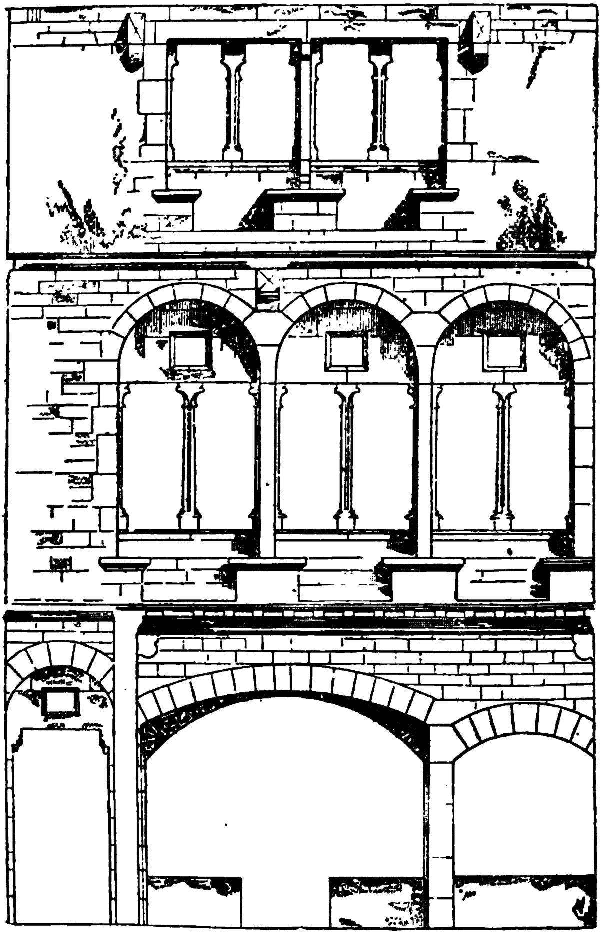

Fig. 117. Interior View of Front shown in Figure 115.

upheld at the ends by wood corbels as shown in the section Figure 118 [see "*Maison*"]. That is the simplest expression of private

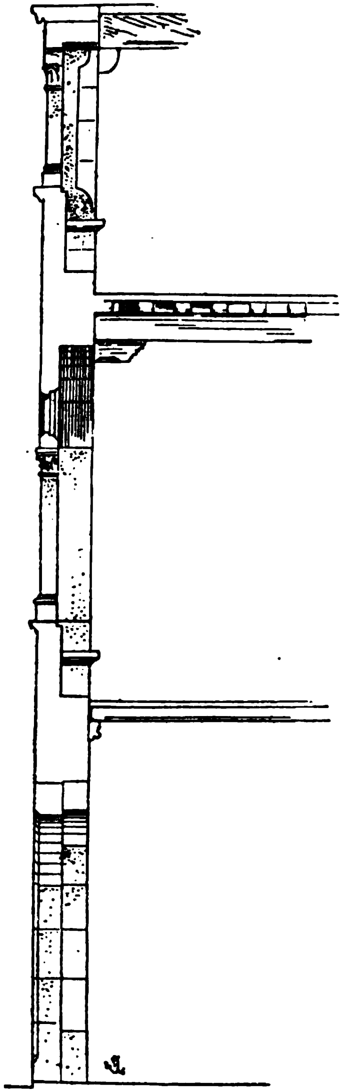

Fig. 118. Section of Figure 115.

architecture during the Middle Ages; but civil construction did not always have such an ingenuous character. In the great dwellings, in the châteaux, the arrangements being much more complicated and the dwellers very numerous, it was necessary to provide interior divisions and separations; nevertheless, there are certain general dispositions which remained the same for the lordly habitations as for those of the citizen. It was always necessary to have the hall, the place of reunion of the family of the citizen or the *maisnée*[1] or household, in the case of the seigneur, then the chambers with their closets and their retiring-rooms and the passage-ways to reach these apartments, with private staircases. There were, then, under the same roof, some very large apartments and others very small, corridors, with air and daylight everywhere. It has been imagined very wrongly that the seignorial dwellings, as well as those of the citizen in the Middle Ages, could not have been other than gloomy and sombre,

[1] The *Maisnée*, that is to say the household, includes not only the family but the servitors, the hired men and women and all the *personnel* of a château.

badly lighted, badly ventilated. This is another of those absolute judgments which one ought not to make concerning this epoch. While the necessities of defence forbade the seigneurs piercing window openings except at rare intervals, they nevertheless sought in their châteaux light, air, view of the landscape, an outlook in various directions and the sun and breeze at will. If one will only take the trouble to reflect a moment he will readily see that men who passed the greater part of their existence in roaming over the country-side would not willingly shut themselves up, sometimes during weeks together, in gloomy rooms, without outlook, without air, without light. If the arrangements for the defence of a residence compelled the dwellers in it to get along with as few exterior windows as possible, if the court-yards of châteaux surrounded with high buildings were frequently gloomy and dark, these dwellers nevertheless sought in all kinds of ingenious ways to get outlooks over the country-side, air and sunshine. This accounts for the flanking turrets, the watch-towers, the battlements, the reëntrant angles which permitted windows to be made, masked from the outside.

Certain special arrangements were also imposed upon the architects of the great dwelling-houses by very sensible customs. It was not permissible during the Middle Ages, any more than during antiquity, to give a large hall and a small chamber the same height between joists; to make a passage-way as lofty as the apartments to which it gave access. Centuries of false reasoning in architecture have been necessary to bring about the neglect of such true principles and to oblige us to live in large low-studded rooms if the story we occupy is low-studded, or in little unreasonably high chambers if we have a story fifteen or twenty feet in the clear. In large cities the height of the stories being governed by regulations, one can understand how necessity has imposed conditions as inconvenient as they are ridiculous. But wherever an architect has free play, in a country-house or in a mansion, it is very unreasonable for him to

neglect to pay attention to the superficial dimensions of apartments so as to fix the height suitable to each of them; to light small chambers or passage-ways by windows having the same dimensions as those used for large apartments; to make lateral corridors obstruct all the light from one of the faces of the building; staircases cut across the middle of window openings; mezzanine stories at the expense of large windows, so that a given architectural style,

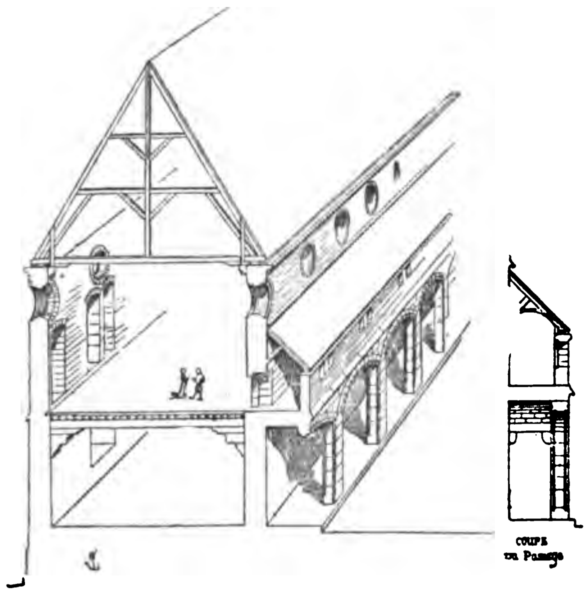

Fig. 119.

which matters very little to the inhabitants of a palace, may not be interfered with; or, still more, to place corridors along the middle of houses giving access to the apartments to the right and left, corridors lighted by borrowed light, badly ventilated, gloomy, noisy as an inn-hallway, taking up valuable space and bringing a weight on the floor-beams in their weakest part. The mediæval architects did

none of these things and did not even imagine that they could be done and they are certainly not the ones to be censured for so thinking. Their dwelling-houses were almost always one room in depth. And in order that the apartments into which they were divided transversely should not open into one another, which would have been very inconvenient in most cases, they arranged lengthwise of these buildings low, covered galleries, which gave access to each of these apartments while still permitting windows to be placed above them (Fig. 119).

If the building had several stories, this arrangement could still be preserved with all its advantages (Fig. 120).

At *A* is seen the second story with its gallery, *C*, above which are the windows lighting the rooms; at *B*, the upper story, almost always open timbered, lighted by windows surmounted by dormers, *E*, on the side opposite to the gallery and by dormers only above this gallery. The passage for the upper story is carried on arches, which permit of window-openings between their vertical faces, lighting directly the second story. Such an arrangement still exists at the Palais de Justice at Paris, in the western portion; it dates from the thirteenth century. We cannot decry the reasonableness and truth shown in such construction, which gives to each household department its relative importance, which supplies to the principal apartments all the air and light they demand and which evidences very clearly by the exterior, the interior uses and arrangements of the structure. It is certainly more in accordance with the good old traditions of antiquity than is a row of columns or pilasters planted, one knows not why, against a wall. It shows that while the mediæval ecclesiastical architecture departed from the ancient models, nevertheless civil architecture was able for a long time to preserve their spirit. We shall note more than one proof of this. When the dwellings are large and the buildings are composed of several stories, a thing which the mediæval architects often sought, for the simple reason that two stories, one above the other, cost

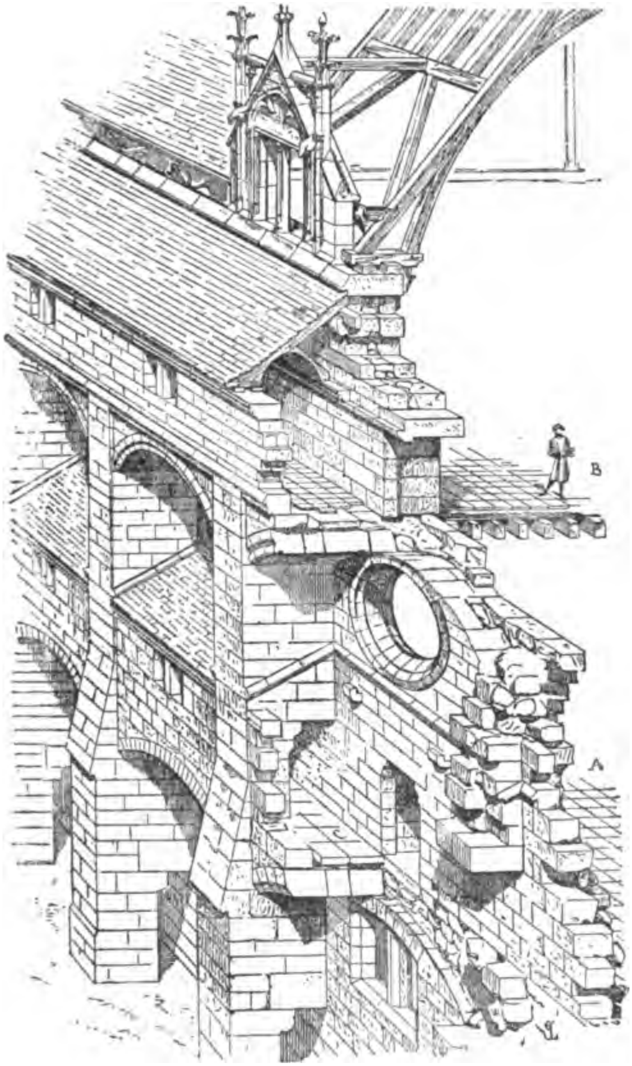

Fig. 120.

less to build than if one undertakes to cover a superficies equal to that of the two stories on the ground-floor, since it is then necessary to double the foundation and the roof—when, we say, the structures contain several stories, the architect increases the number of stairways so that each apartment has its own. Nevertheless there is always a principal flight, a staircase of honor which leads to the apartments intended for receptions. During the Romanesque period, stairs of cut stone are not common; they were usually made of timber, that is to say by superposing squared logs, whose ends are slightly let into the lateral walls; later staircases were made of two straight flights with landings and were included in a rectangular cage, longitudinally traversed by a bearing-wall [See "*Escalier*"]. This method was almost entirely abandoned by the constructors of the thirteenth century, who adopted spiral staircases with stone newels and treads because they occupied less room and gave easier access to the stories which were to be reached. If these spiral staircases had a very small diameter, say five feet in the clear, they were frequently built in the thickness of the walls, forming a slight projection on the outside rather than on the inside; if, on the contrary, they occupied a cylindrical or polygonal cage of considerable diameter in the clear, say eight or ten feet, they projected entirely on the exterior and did not interfere with the internal arrangements. As for the separate buildings, each possessed its own roof and if the structures were of double extent, there was a roof over each portion with an intermediate gutter. The mediæval architects having felt compelled to adopt roofs whose slope was more than 45° and having no conception of gambrel roofs could not understand a structure of double extent under one single roof, for this roof would then have reached an enormous dimension as far as the height is concerned. It was easy to place, if need be, roofs at different levels on every detached building, every pavilion, every staircase, possessing its own roof, whether pyramidal, lean-to, gabled or hipped and thus to obtain stories high between joists when they were large, or low when they

were small. This method used a great deal of wood and roof-surface and required lead-lined gutters, but it had this advantage over that which consists in enveloping all the parts of a building under one roof, viz, that it furnished to architects various resources in respect to giving height to stories, of permitting them to open a large number of dormers, to illuminate the upper stories, of detaching the staircase roof from the main roof, thus providing lookouts above the eaves and acting as ventilators for the lower stories. Seen from a distance these distinct roofs covering groups of connected buildings, indicating their form and their purpose, were very picturesque and gave to large dwellings the appearance of a collection of houses of greater or less extent and height according to their various uses.

It is easy to be seen that this construction differed at all points from that of our own times and it should be remarked that these traditions preserved their force until toward the middle of the seventeenth century. In principle if not in form we note in these arrangements the trace of the great dwellings of antiquity, the *villæ*, which were in truth nothing but groups of buildings more or less connected, but distinct in form, in height and in roofing. Careless of the laws of symmetry the mediæval architects placed the different departments of the large dwellings anywhere according to orientation, with due regard to the needs of the dwellers and conformably to the configuration of the ground. This furnishes another point of resemblance to the antique *villæ* which in their *ensemble* had nothing symmetrical. In the cities which were almost all fortified at that time, ground was as rare as it was in the fortified towns. In the châteaux whose perimeter was always limited as much by motives of economy as by the necessity of defending it by a small garrison, every foot of space was utilized. Consequently the architects had to endeavor in town as well as in the country to accommodate as many household needs as possible in a relatively small space. In this regard the mediæval civil constructions differ from those of the ancients; the latter in their *villæ* scarcely built higher than one

story and occupied considerable ground. Obliged to confine themselves within restricted limits, the architects of the Middle Ages were compelled to adopt interior arrangements differing likewise from those employed by the Romans; to accommodate various kinds of work on different stories; to make passage-ways in the thickness of the walls; in short, to seek entirely new combinations of structures. We do not forget, however, this important point, that one reason why the ancient traditions perpetuate themselves in civil constructions is the very natural one that everything concerning everyday life transmits itself from generation to generation without possibility of interruption, that domestic habits cannot be abruptly changed and that it is possible to make a radical revolution in the system of construction of public monuments, like churches, while this is impossible for the dwellings or palaces which people live in and in which everybody follows the same way of living which his father followed. The method of construction applied at the end of the twelfth century to religious edifices has only a feeble influence on civil edifices.

The pointed arch had scarcely appeared in these last edifices bringing its wide-reaching train of consequences as we have shown.

Civil and military construction preserved something of Roman art even when the last traces of this art had long since been abandoned in religious architecture. There were then two quite distinct modes of building dating from the end of the twelfth century: the religious and the civil; and this state of things lasted until toward the middle of the sixteenth century. The monasteries even use both of these methods together; their domiciles have no relation, so far as construction goes, with their churches or their chapels. Nevertheless, one of the principal attributes of construction at the moment when it abandons Roman traditions, daring, is found also in civil as well as in ecclesiastical architecture; but, it is evident in civil architecture, that the positive ideas, the daily needs, the inherited habits have a more direct influence on the methods adopted by the builder. Thus, for example, rock-faced rubble is used in civil architecture for

a long time after all religious constructions were made of cut stone; horizontal arches of stone were everywhere applied to dwellings in the twelfth, thirteenth, fourteenth and fifteenth centuries, at a time when no trace of them was longer to be found in churches.

Buttresses are avoided as much as possible on the exterior of palaces and mansions, even where there exist vaulted stories, while they constitute the entire system of ecclesiastical construction. The civil architects still continued to employ wood, whereas this is used only for the roofs of cathedrals and other important religious edifices. Seeking to avoid solids, to diminish points of support, they

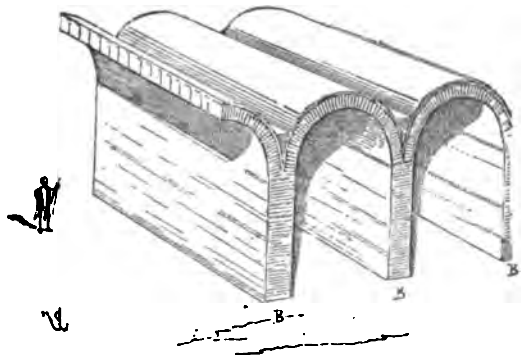

Fig. 121.

at last reached the point of totally suppressing walls in rearing their grand religious edifices; on the other hand, in civil architecture they augmented the thickness of the walls in proportion as prosperous conditions obtained, which created a demand for more comfortable, stronger and healthier houses. The study of these two sorts of buildings should then be followed up separately and if we find inevitable points of similarity between these two systems, it will be less in the methods used than in the frank and daring charm, the infinite resources, which belong to the lay architects of mediæval times.

All who have any notion of architecture know that the Romans, while indeed they constructed vaulted edifices, maintained the thrust of the vaults rather by interior buttresses than by piers forming an external projection. They had adopted, especially in building civil structures, the method which we shall call cellular; that is to say, they made their buildings of a series of rooms with barrel-vaults on bearing-walls which reciprocally buttressed each other and thus cansed no thrust on the exterior. From this principle sufficiently demonstrated by Figure 121 result the consequences which might naturally be expected. If, for example, it was desired to make a single room out of all these clustered cells, it was only necessary to throw a longitudinal barrel-vault across all these transverse barrel-vaults; there resulted a succession of groins, Figure 122, well buttressed by interior counterforts, letter A the remains of the bearing walls B shown in perspective in the sketch, Figure 121. This arrangement permitted building at C either solid walls or spaces as light as possible, as there was no weight on them. This was both a simple and durable construction, easy to build and which answered for a long time as the type of civil edifices in the Carlovingian epoch.

In order to avoid expense and if vaults were not preferred, during the Roman period they contented themselves with laying floors on top of two parallel ranges of semicircular arches. In this way several stories could be built one above the other without fear of having the lateral walls spread, since they were composed of buttresses furnishing a succession of interior piers and united together by arches which intersected; underneath these arches as many openings were made as necessity demanded for furnishing air and light to the rooms. Figures 115, 116, 117, 118 which show us one of the houses built in the thirteenth century, in the town of Cluny, still preserve the remnants of this Roman tradition, as the front of this house really consists of nothing else but a series of bearing arches masked behind the exterior facing. If this combination lent itself to the most prosaic civil constructions, it was equally suitable for military

purposes, as we shall very soon see; it was still later applied to the construction of the great halls of the châteaux and Episcopal residences, since the hall of Henri II at Fontainebleau shows us one of the latest examples of it, seen likewise in a thirteenth-century room in the close of the castle of Montargis and also still to be seen in an ancient diocesan hall of the twelfth century at Angiers near the cathedral, both of these latter being built according to this principle [See "*Salle*"].

A very important thing to notice in the mediæval civil constructions is the attention which the builders paid to the smallest details

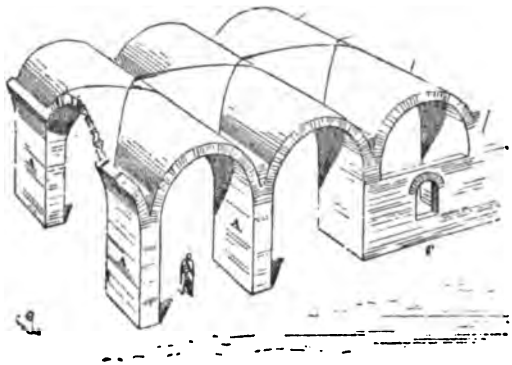

Fig. 122.

of the structure. If they are about to make a floor, well squared holes are left for the girders in the interior faces of the walls instead of cutting them out afterwards; they build-in stone corbels under the bearing ends of these girders; they make horizontal rebates lengthwise of the bearing walls to receive the headers into which the tail-beams are framed or else open bearings at regularly spaced intervals. In the embrasures of the windows they built in the hinges; they made rebates in the interior of the mullions to receive the staples of the bolts or locks. Their chimneys built at the same

time as the walls have the flues dressed on the inside with the greatest care; the jambs of the fireplaces are bonded into the walls and not simply built up against them; the passage of the flues through the flooring and the supports of the upper hearths indicate great carefulness and a plan well thought out before the work was begun. All these things would teach us an excellent lesson to-day, if we were willing to consider and rid ourselves of this mania of believing that we can obtain no good from the past when that past is a cis-alpine one.

In the large civil structures, such as the assembly-rooms or "Halles," the mediæval builders are almost always careful to introduce lower and upper windows; the low ones enable one to see what transpires outside and admit air; the upper ones admit light directly from above. These upper windows are made in the slope of the roof and form dormers on its exterior. Whatever the superficial extent or height of the room, the windows were always kept of a size convenient for use by men and women and, what is still more important, of a reasonable size for sashes intended to be frequently opened. So far as the dormer sashes are concerned they were opened like a lid of a box by means of cords and pulleys [See "*Lucarne*"].[1]

One is too easily tempted to believe that however ingenious the

[1] These dormers faced with stone were used in building from the thirteenth century onward and, nevertheless, in the time of Louis XIV, it was pretended that this method of making windows at the eaves of a roof was invented by Mansard; and in order to perpetuate the remembrance of this useful invention the term of "mansards" has been applied from that time onward to this sort of windows just as if all the civil buildings, the châteaux and the mansions had not been provided with mansards in the time of Francis I, Louis XII, and long before their times. But this is one of the weaknesses of the seventeenth century which claimed to have discovered everything. But this is only a claim. It is in this case as in many others of the same epoch. It has been written and said many times, that the wheelbarrow, for instance, was invented in the seventeenth century, at the time when the great work of terracing at Versailles was undertaken; but we have numerous examples of wheelbarrows figured on the manuscripts and painted windows of the thirteenth century. It is true that the form of these little vehicles at this epoch is much more convenient for the laborer than that adopted later than the seventeenth century which we reproduce religiously in our workshops as if it were a masterpiece. It is the same way with the dray, invented, so it is said, by Pascal.

mediæval architects may have been they could not form those large conceptions of *ensemble*, those vast buildings of a civil character demanded by our modern necessities which assume every day more and more importance: but this is another prejudice. It must be said that most of our great churches still standing to-day make us see plainly that in ecclesiastical architecture the constructors knew how to begin and carry through very vast monuments; but as for the civil structures of the Middle Age, cruelly treated during the last few centuries, condemned to systematic destruction since the Revolution, scorned by our French administrations of Public Works, who recall on a small scale the weakness of Louis XIV and seem to wish that everything in their town shall bear trace of their passage — our civil structures of an ancient date, we repeat, have become very rare and it is not surprising that the people have lost even the memory of them. Nevertheless it would have been very strange if men capable of conceiving and executing such immense religious edifices had contented themselves, for the ordinary needs of life, with small buildings covering but little ground, low, narrow species of cabins, of miserable appearance. There are certain persons who would wish to make us believe, as a consequence of a spirit of system which it is not now our place to criticise, because it is completely a stranger to artistic ideas, that mediæval society was shut up between the church and the fortress; that it was in consequence, unfitted to conceive and execute these immense structures of public utility demanded by our modern customs; in short, that it lived a miserable life, suffocated under two kinds of oppression, frequently antagonistic, but always united for the purpose of arresting its development. From the standpoint of politics the fact may be discussed, that is not in our line; but from the standpoint of art there can be no discussion. The artists who drew the plans of our cathedrals were not at all embarrassed when it came to constructing those immense civil establishments, such as hospitals, colleges, town-halls, markets, farm-houses amply provided with all appurtenances.

To architects, it is of small importance to know whether these hospitals, these colleges, these farm-houses were dependencies of abbeys or cloisters, whether these town-halls were frequently bullied by the suzerains, whether these markets paid a tribute to the lord of the manor. These establishments existed, that is all we need to state; they were well arranged, well constructed, in a durable and thoughtful way; that we must acknowledge.[1]

Let us take a few examples; let us examine the excellent arrangements of the great halls of the abbey of Ourscamp, of S. Jean-des-Vignes, at Soissons, of Mont S. Michel, and of the hospitals of Angers[2] and Chartres, which date from the end of the twelfth and the beginning of the thirteenth century. Where shall we find better construction, better conceptions, more ample, more healthful, without needless luxury and which give a higher idea of the knowledge and practical sense of their architects?

The general view and details of some of these vast edifices having been engraved with minute care in the work of M. Verdier on civil architecture, we do not deem it necessary to reproduce them here; we shall give our readers a few constructions which have not before been studied and which have, at least, an equal importance with those mentioned. There existed in the Abbey of S. Marie de Breteuil, a large building flanked by four turrets and crenellated, which could, if necessary, be defended. Its ground-floor contained the kitchens and their dependencies. The second story contained the dormitories of the guests of the monastery; the third, a large infirmary; the fourth,

[1] The spirit of passion which causes the destruction of castles and even churches is comprehensible; but what is much more difficult to explain is the blind mania which has brought about in France during the last sixty years the demolition of numbers of very good civil structures, very handsome, very useful (for no other reason than that they were old and recalled a former age), simply to replace them by deplorable constructions which cost a great deal of money, although they were built in a parsimonious manner and are frequently decidedly ugly. Many towns have been deprived of establishments which would have been suitable for new uses, which would attract the attention of travellers and which, in short, did them honor.

[2] See "*Architecture, Civil et Domestique*," de MM. Aymar Verdier et Cattois.

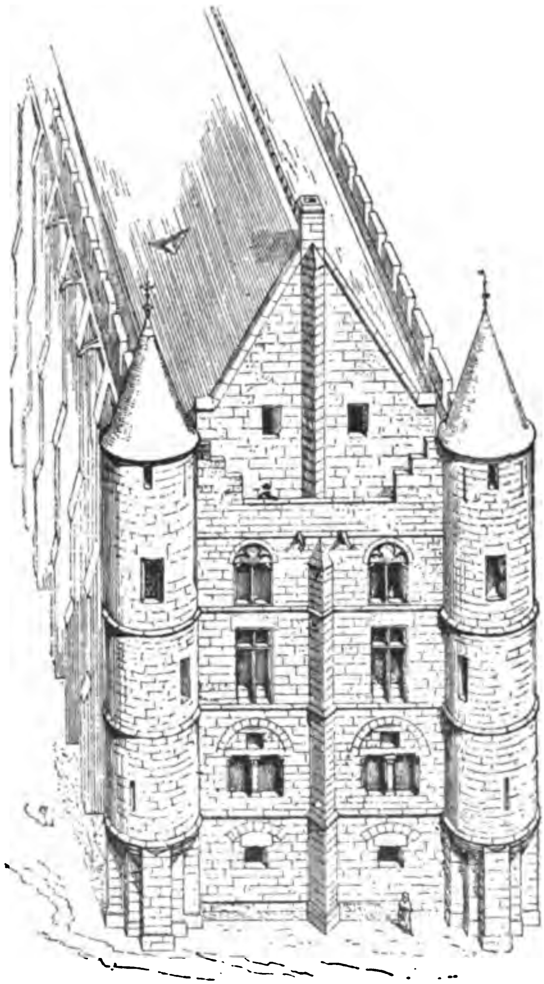

Fig. 123. Abbey of S. Marie de Breteuil, France.

store-rooms for provisions and the garret, under the roof, a granary for storing cereals. A lateral staircase passing through the buttresses

and covered by a lean-to roof rose to the third story; the turrets at the angles had, in addition, winding staircases leading from one story to the other. This structure was not vaulted except the lower floor and under the roof; it is divided lengthwise by a range of columns. Lateral buttresses take the thrust of the vaults.

Figure 123 shows the exterior aspect of this structure.[1] We see the gable on which is built the huge kitchen chimney. A triangular buttress, like a ship's prow, gives strength to this gable wall

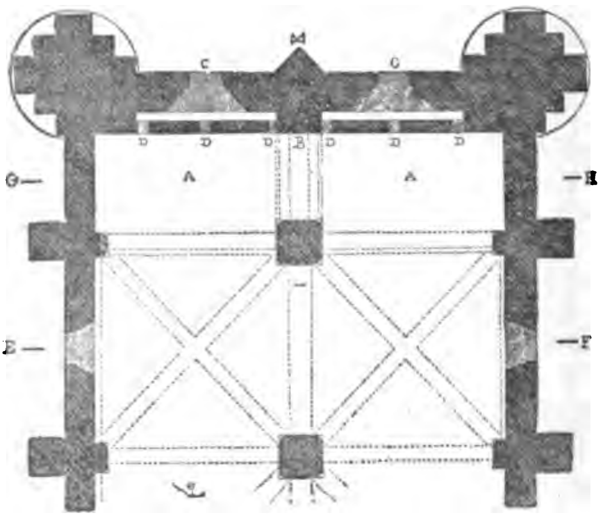

Fig. 123*a*.

in front of the chimney-flue. In order to grasp this construction thoroughly, it is necessary to refer to the plan (123*a*) taken on the ground-floor level. The entire space *A A*, that is to say the last bay of the room, is occupied by the fireplace whose flue rises at *B* between two arches. At *C* are exterior openings communicating by a throat with the air inlets intended to give a vigorous draft to the fire built on an elevated grate and to establish a sufficient

[1] See "*Monog. d'abbayes.*" Bib. Sainte Geneviève.

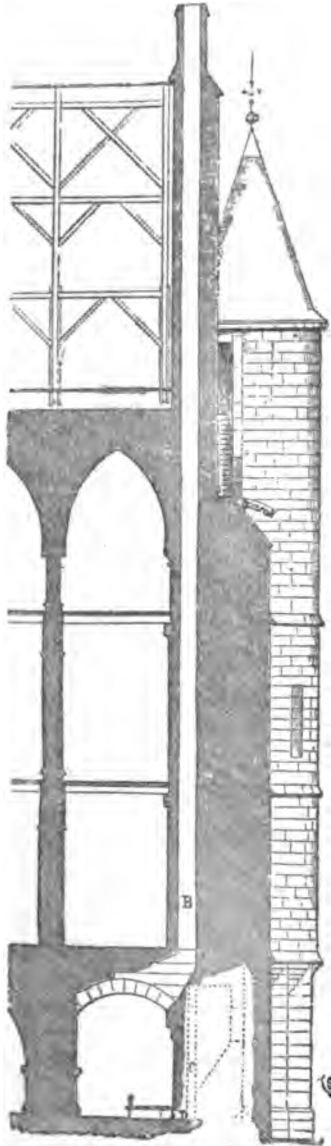

Fig. 123*b*.

current of air to carry away the smoke into the central flue. Figure 123*b* made on the line *I K* of the plan, shows us at *B*, the chimney-flue, at *C* the throat with its exterior opening, and at *D* the air-inlets. It will be observed that the pathway around the battlements is not interfered with by the turrets and the gables, but, on the contrary, that this pathway is continuous across the gables on a lower level. Figure 123*c* shows at *A*, the section of the ground-floor on the line *E F* of the plan and at *B* this section on the line *G H*. In the section *A* are shown at *C* the arches which form the hood of the chimney divided by the large pillar; at *D* the mouths of the air-inlets with the elevated grate. In the section *B* the arches *M* which form the soffit of the chimney are of brick and the flue is shown by the dotted lines at *O*. The dotted lines also show at *P* the two air-intakes intended to supply the inlets by the throat behind the brick wall which forms the back of the fireplace.

The cross-section (Fig. 124) looking toward the gable

opposite to the chimney, completes the description of this fine and simple construction. At *A* is shown the lateral staircase which leads up to the second story through the buttresses, which are given greater projection in order to provide for it. The windows *B* of the third story used for store-rooms are pierced in the gable on the level of the interior flooring so as to facilitate the hoisting up, by pulleys supported on exterior brackets, of the things to be stored. Similarly the openings *C* are pierced on the level of the floor of the garret. The thick side walls preserve an equable temperature in

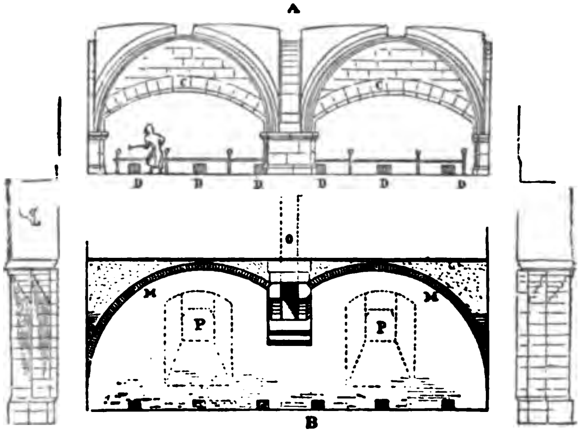

Fig. 123c.

the interior; the ventilation of the stories could easily be managed, by means of windows opened in the four main walls on all sides of the isolated building. The buttresses enclosing the walls dispense with all transverse anchorage and this the more naturally because the inner face of the walls frequently overhung the story below, as shown in the transverse section, Figure 124.

This was a means frequently employed to give the walls an inclination inwards, and is, in fact, an excellent principle of construction whenever one is able to give to the base of the walls, sufficient

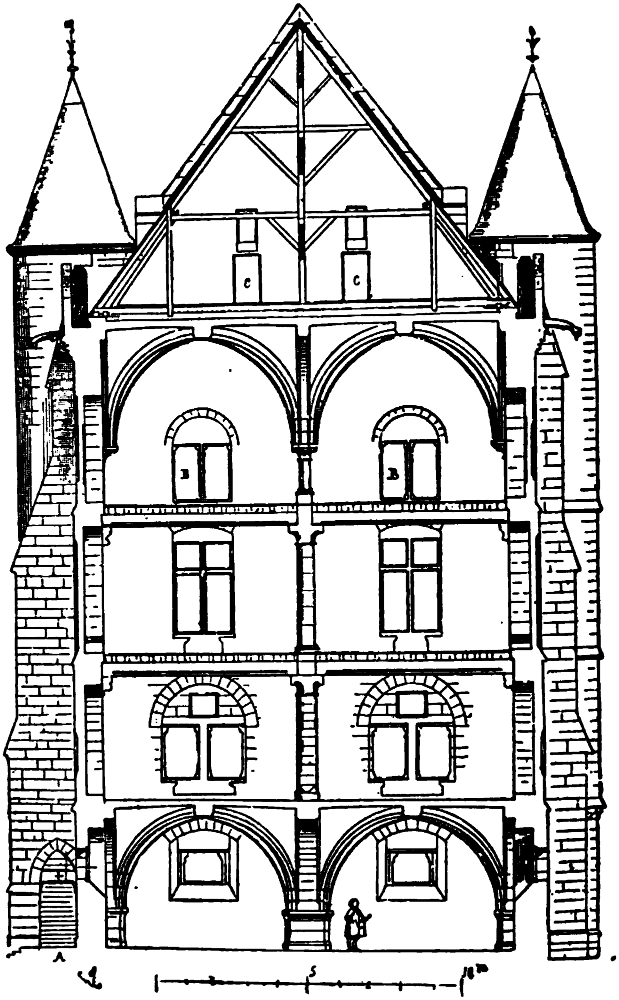

Fig. 124.

thickness to guard against danger of buckling. It must be remarked, nevertheless, that habitually the intermediate girders (see the

transverse section) do not tie together the bearing or side walls [*murs-goutterots*]; observe how the ends of the girders on the intermediate columns are arranged. At each story the supports are furnished with a cap *A* (Fig. 125), projecting only under the girder

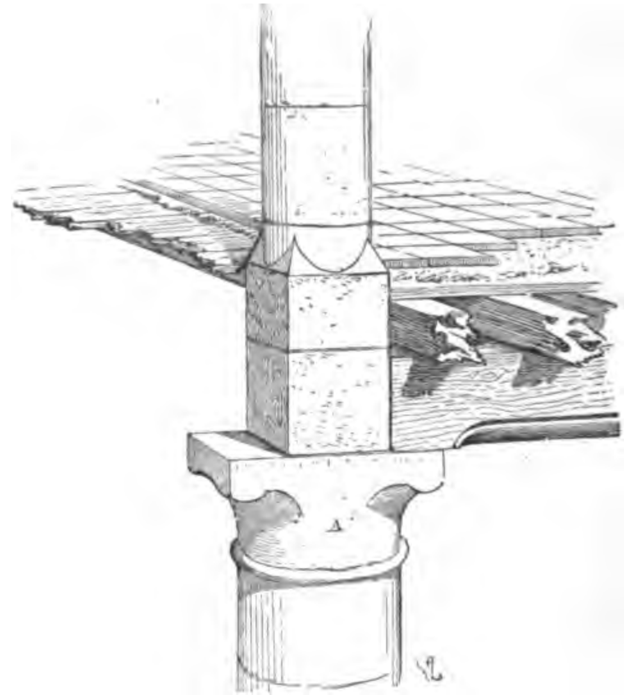

Fig. 125.

ends. Consequently the bearing walls exert a pressure on these girders and not a pull.

We may not follow this plan in our modern constructions, but it is not without its advantages, and the Greeks in ancient times, much earlier than the epoch we are considering, had followed it in building their temples. If the mediæval architects followed the laws of

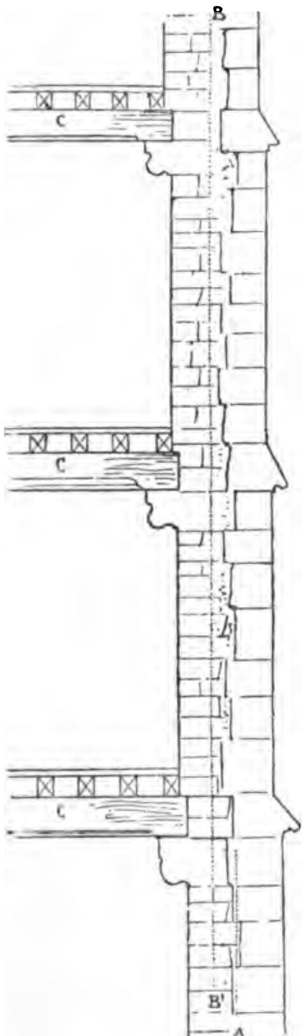

Fig. 126.

equilibrium, whose importance we have endeavored to show, in building the vast vaulted edifices carried on isolated supports, they, at the same time, sought to obtain the concentration, the resultant of all the forces acting toward the centre of their edifices, in such a way that all the parts had a certain disposition to reciprocally buttress one another.

In civil constructions, where vaults play only a secondary rôle, where the floors present horizontal and rigid surfaces at different heights, the constructors adopt methods of building which act from the outside inwards against these rigid surfaces. They reached this result by the arrangement of the general plan and special details of construction. For instance, they give the walls an interior overhang, as we have just mentioned, and they build these walls of large stones on the outside and with courses of less height, or with rubble on the inside.

Take, for instance, the section of a wall *A-B*, intended to carry the girders (Fig. 126); the outer face of this wall will be composed of relatively high courses of stone not bonded, and each story, separated by a stone belt-course, will be set a

few centimetres farther back than the one below. The interior face, on the contrary, will be laid with thinner stones and each story will overhang the one below. Therefore, this wall will have a tendency to lean inwards — first, because its axis B will fall at B', inside the lower axis A; second, because the exterior face will offer a less compressible surface than does the interior face. Thus, this wall constructed in this manner will exert against the ends of the girders C, a more powerful pressure in proportion as these girders are elevated above the ground. It would be, therefore, superfluous to tie the walls, which instead of tending to spread, will have on the other hand, a tendency to incline inwards.

This example shows that while the civil construction of mediæval times has its own individual character, distinct from religious construction, the architects, nevertheless, endeavor to replace in one as in the other inert masses by acting forces. In the civil constructions, the floors are considered as braces placed between walls which tend toward one another. Thus these floors are stiffened by the pressure of the walls and the whole mass of the building shows great solidity in consequence of these pressures against a system of braces.

The mediæval builders give proof of a great deal of independence in the combinations of vaults belonging to civil edifices; everything suits their purpose, according to the occasion or necessity: the cradle vault, the Roman groined vault, the pointed, semicircular or stilted Gothic vault, the vaults composed of ranges of arches supporting ceilings or pendentives. When they no longer followed any but one sort of vaulting in ecclesiastical architecture, that is to say during the thirteenth and fourteenth centuries, they had, nevertheless, the good sense not to apply this system, only in so far as it offered advantages in civil constructions. Frequently very wide buildings necessitated the erection on the interior of one or two rows of supports to carry the floors of the upper stories, as we have before observed; in this case the ground-floor was generally vaulted; but as these slender

supports placed one above the other and only braced by the floors had no stability, they did what they could to give them sufficient base, at least on the lower piers carrying the vaults, and fearing to crush the skew-backs of these vaults under the load, they made them independent of the piers.

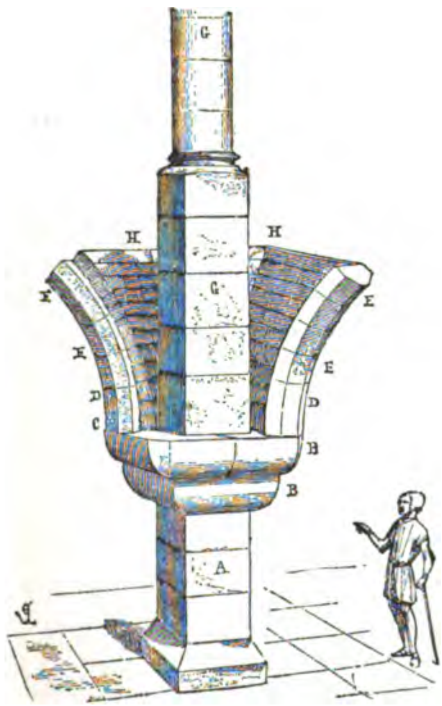

Fig. 127.

Thus, for example (127): given a pier A of the ground-floor intended to carry vaults; they laid on this pier two or three courses, B, making corbels on the four faces; thus a shoulder C was obtained. At the angles were placed skew-backs D following the diagonals of the squares, to receive the voussoirs E of the vault; in the centre, the pier G was carried up free to receive the upper timbers, then the vault spandrel H was filled with rubble. Neither the skew-backs of these vaults nor their spandrels carried any load and the masonry of the haunches only braced the piers. Fearing on the ground-floor the action of the thrusts on walls, which were not always buttressed, the builders frequently made very heavy corbels along these walls to diminish as much as possible the thrusts and disperse their resultant

over the entire wall, or even over the interior facing only. Upon these corbels they were then able to place segmental arches which required less rise. Abandoning groined or pointed vaults, they carried vertical tympani *B*, on the large arches *A*, perpendicular to the walls (128), up to the level of the extrados of the key of

Fig. 128.

these arches, *A*; then they sprung over these tympani segmental cradle vaults, *C*. In this way they succeeded in vaulting over large spaces without requiring much rise and without lowering the springings so much as to interfere with the passageway. By multiplying and bringing these arches nearer together they were able to replace the vaultings *C*, with flags making a floor placed on stone purlins (if

materials were suitable), as shown in Figure 129. These purlins had rebates, thus bringing their upper surfaces level with the flags shown by dotted line *E-F*. These methods of building obtained for a long time without sensible modifications, for we still see constructions of the fifteenth century which reproduce these simple, imposing

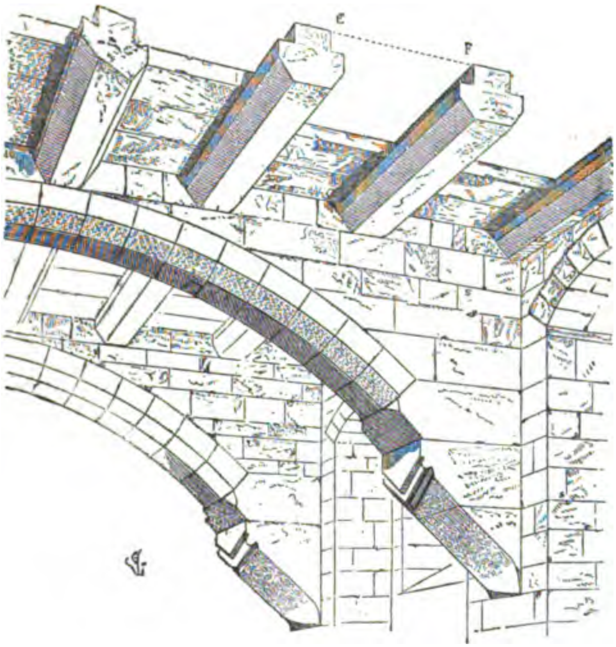

Fig. 129.

and severe dispositions. The finest example which we know of these civil constructions, in which corbels play a very important part, is the castle of Hoh-Kœnigsbourg, near Schelestadt.[1]

One could almost take the principal rooms of this Château for

[1] See the ground plan of this Château under the word *Château*, Figures 30, 31, room M.

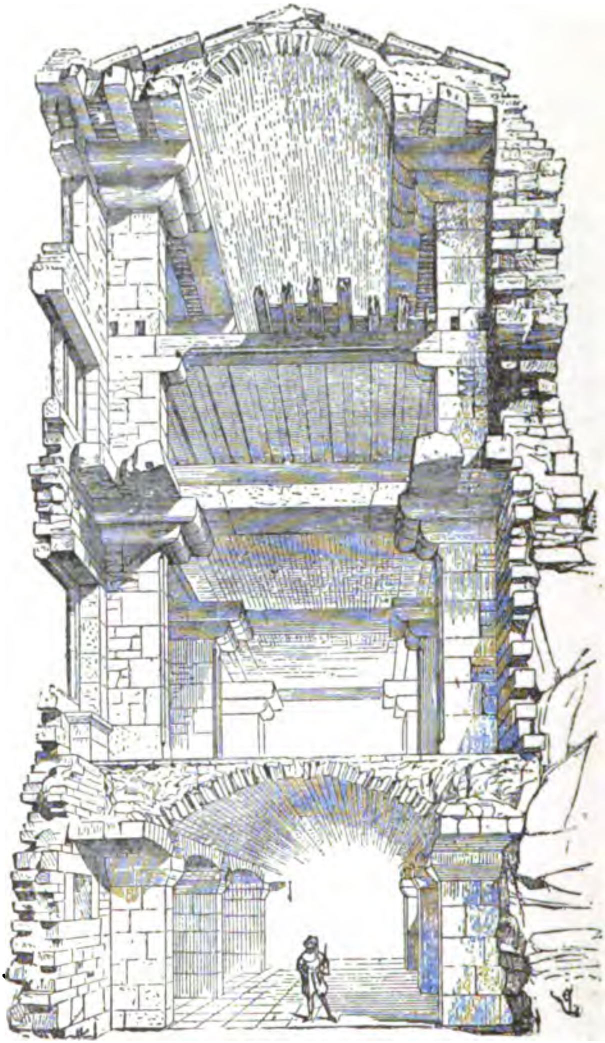

Fig. 130. Castle at Hoh-Kœnigsbourg.

thirteenth-century constructions, whereas, they were not built until the fifteenth century.

But Alsace had kept the good old traditions of the Gothic epoch, especially in civil architecture. The principal building of the Château Hoh-Kœnigsbourg abutting against the rock (130), is built only of interior buttresses with a very thin exterior wall on the court side. It has four stories; the ground-floor, which was used for a kitchen, has a segmental-cradle vault resting on very flat arches of ashlar, sprung from one pier to the other. The first story is ceiled by means of large dressed lintels, carried by strong corbels; the parallelograms left void between the lintels are filled with rubble. The second story is covered by a wooden flooring whose principal girders are carried on corbels built into the piers. A third story has a semi-circular cradle vault, resting upon lintels — and on large corbels similarly arranged to the first story. This upper vault carries a platform or terrace covered by flags. The perspective section (Fig. 130) gives the general appearance of this peculiar construction. It should be stated that the local materials (a reddish sandstone) are adapted to these bold methods; the employment of such thin lintels, of such wide span, would be inadmissible for us with our calcareous materials from the Seine, Oise or Aisne valleys.[1]

But in civil and military architecture, even more than in ecclesiastical architecture, the nature of the materials had a very marked influence in the selection of methods of construction; this example is a proof of it. The longitudinal lintels between the buttresses and the transversal ones from one buttress to another have voussoir joints. If we make a longitudinal section of this building, each bay gives us (Fig. 131).[2]

It is impossible for one to form an idea of the majestic grandeur of these buildings unless he has seen them. Luxury is not considered

[1] In the sixteenth century an accident compelled the owners of Hoh-Kœnigsbourg to spring arches under the ceilings of the first story.

[2] M. Bœswilwald, who has made plans of the Château of Hoh-Kœnigsbourg with the greatest care, has been kind enough to put his drawings at our disposal.

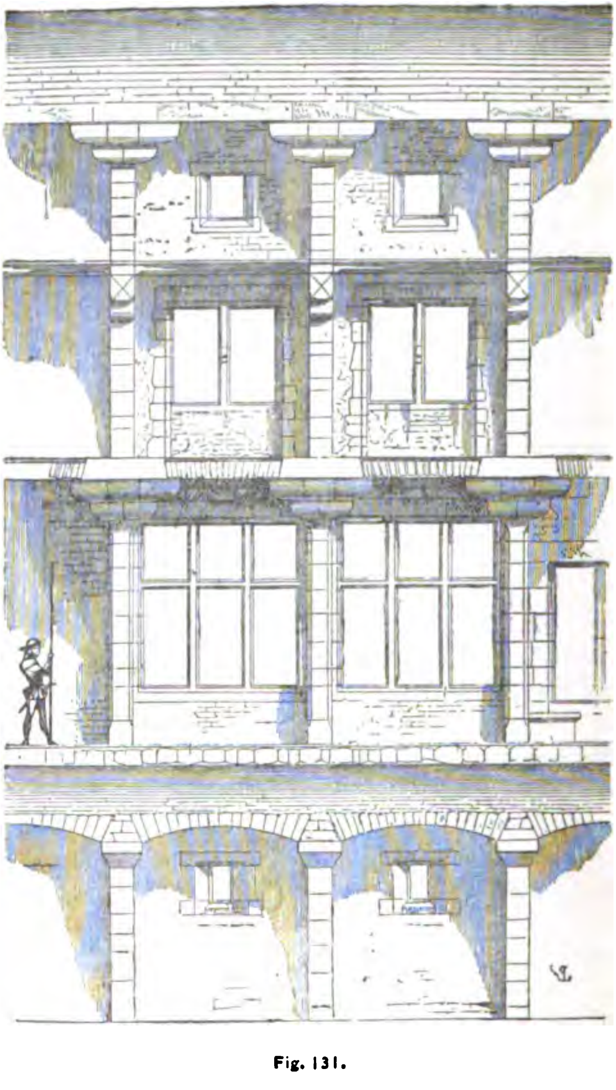

Fig. 131.

here; it is pure construction and the architecture takes no other form than that imposed by the judicious employment of the materials; the principal points of support and the lintels are alone in cut stone, the rest of the structure in stuccoed rubble. We are free to admit that this way of understanding civil architecture has a peculiar attraction for us. It should be said that the Château of Hoh-Kœnigsbourg is built on the summit of a high mountain, eight months of the year surrounded by snow and fog, and that in such a situation it would have been very ridiculous to choose architectonic forms which could only have been appreciated by the eagles and the vultures; that the savage aspect of these structures is in perfect harmony with the ruggedness of the place.

In this connection we shall be permitted to make an important observation. We think ourselves the first to appreciate that which is called the *picturesque*, because since the seventeenth century no one has found any beauty, except in parks planted *à la Française*, in right-angled and symmetrical buildings, in terraces veneered with stones and cascades with lead-lined channels. Without denying the value of nature thus arranged by art, we must, nevertheless, recognize the fact that nature left to herself is more varied, more free, more grandiose and more essentially beautiful. A Seignior of the Court of Louis Fourteenth or of Louis Fifteenth would very much prefer the parks of Versailles or Sceaux, to the wild vistas of the gorges of the Alps or the Pyrenees; the Duke of St. Simon, who had no office at Court, preferred to dwell in a narrow and gloomy apartment at Versailles than to live in his charming residence, *la Ferté*. But our mediæval lords were, on the contrary, sensible to these natural beauties, they loved them because they dwelt among them. Without speaking of the very lively appreciation of nature to be found in the numerous romances of the Middle Ages, we see the castles, the manors, the abbeys, are always so situated as to give their inhabitants views of the surrounding localities.

Their construction harmonizes with these localities; wild and

imposing in abrupt places; fine and elegant at the foot of laughing slopes, on the banks of tranquil rivers, in the midst of verdant plains. In these houses, the views of the most picturesque points are always arranged with skill and in such fashion as to present unexpected and varied aspects. In studying the civil constructions of mediæval times, it is, therefore, necessary to take into consideration the locality, the nature of the climate, the site, for all these things exercise an influence on the builder.

A building which is suitably arranged and constructed on a level site, in a country of gentle and tranquil aspect, would be ridiculous on the top of a savage cliff surrounded by precipices. Another one by its severe and even harsh character seems to grow out of the desolate soil where it rises, but would appear deformed and coarse surrounded by fields and meadows.

Those barbarous men, as they are considered by most people, were then sensible to natural beauties and their dwellings reflected, so to speak, these different sorts of beauty — harmonized with them. We, who are civilized and who pretend to have invented the *picturesque*, build elegant pavilions on some rustic site, which seems to have been intended to carry a fortress; and we build massive structures on the bank of a streamlet running through a meadow. This would lead us to believe that these mediæval barbarians loved and understood nature, without making much ado over it and that we, who boast of it on every occasion in prose and in verse, look at it with a careless eye, without being sensible to its beauties. Centuries are like individuals, they wish always to be considered gifted with the qualities which are wanting in them and care very little for those which they do possess. Everybody fought for religion in the sixteenth century and nine-tenths of the combatants on both sides did not even believe in God. They prided themselves on chivalry and on refined manners in the seventeenth century and their minds turned very strongly, even at that epoch, toward positive ideas and the satisfaction of material wants. In the eighteenth century

they conversed only about *virtue, nature, gentle philosophy,* when virtue was scarcely in vogue, when nature was looked at through the glazed window of one's chamber and in lieu of gentle philosophy, the only sort which was practised was founded on the assured well-being of one's self and one's friends.

But to return to our buildings: the system of corbelled construc-

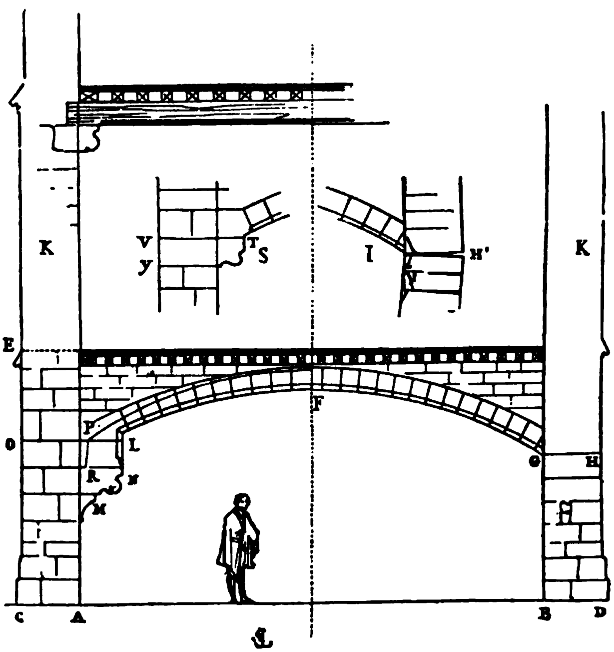

Fig. 132.

tions was very much in vogue from the twelfth century in civil structures; it is, in fact, economical and full of resources, whether for carrying floors, for avoiding very great thickness of walls and considerable foundations, receiving the framing, carrying the over-hangs, obtaining more extensive surfaces in the upper stories of buildings than on the ground-floor, providing for subdivisions for

communicating staircases from one story to another, offering shelter, etc. It was another application of that principle of the mediæval architects, which consisted in employing active forces instead of passive forces; for a corbel is a lever which needs a counterpoise in order to fulfil its function. Corbels have the advantage of not producing any thrusts, always difficult to counterbalance in constructions where the apartments are planned for special purposes, with thin walls cutting one another irregularly. They require less rise than arches, or can neutralize their thrust by placing the skew-backs outside the face of the walls, which is easily demonstrated. Let *AB* (132) be the opening of a room whose flooring is supported by arches, as was shown in Figures 128, 129; *AC*, *BD*, the thickness of the walls; *CE* the height between joists. If we carry the arch *GF* on the wall, even admitting that we have a heavy weight at K, there is reason to fear that we shall exercise such a thrust from *G* to *H* that the wall will buckle outwards, for the resistance of the friction of the bed *GH* will not be sufficient to prevent a slip; or if there is no slip, the length *GH* is not such that the bed may not open outside and fall off inside, as is shown at *I*, an effect which will produce a buckling of the wall and consequently the fall of the arches. But if we have a strongly projecting skew-back *L*, and two corbel courses *MN*, and supposing that *K'* is a reasonable weight, we can counteract the slip by a much more extended bed *LO* and by a greater friction; the curve of resistance exercised by the arch, which curve touches the bed *LO*, at *P*, will meet there a resistance which will resolve itself into a line *PR*, more or less inclined according as the weight of the upper load *K'* is less or greater.

If this load is a heavy one from the point *R*, the resultant of the thrusts might become vertical, and fall within the interior face of the wall, which would matter little; that is all that we could expect.

The builder took the precaution in this case of putting, at least, one course with its interior face vertical to the perpendicular from the meeting of the arch with the corbelled skew-back, for he thus

augments the resistance to the thrust by the friction of the beds of two stones; while if he put only one corbel course under the skew-back, as indicated at *S*, he would have only the resistance of the bed *TV* to counteract the thrust, and the buckling of the wall might result at *Y* as it did at *H'*. When builders could not for any cause give to their corbelling the height of three or four courses, they obtained very resistant stones and (133) they placed them with sufficient projection as shown in section *A*, to make the curve of pressure of the arch fall at *B* within the interior face of the wall; this gives the stone *A* a lever action — they, therefore, support it by a slight projection *C*; its lever movement would then describe the arc of a circle of which *D* is the centre. To overcome this lever movement there is the weight *E* beside that of the masonry spandrel *F*. The leverage being overcome, the corbel *A* has no other tendency than to slip from *B* toward *G*. Then the problem is to make the friction sufficiently great on this bed *DG* by means of the vertical weight *E* to prevent this slipping. Corbels then possess two properties: that of carrying weights on the principle of levers heavily weighted by the load at one end, and the action of resistance to oblique thrusts by the augmentation of the surfaces of friction. Thus we see that in all cases the mediæval builders employed active resistances, that is to say a system of equilibrium, instead of the principle of passive resistance of the Roman construction.

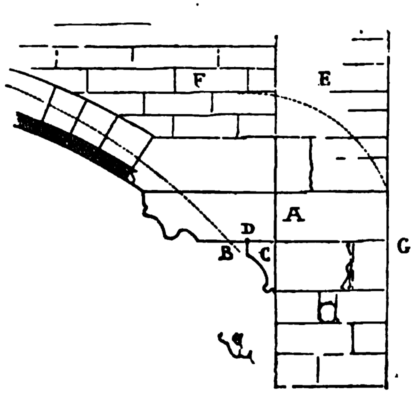

Fig. 133.

As was always their custom, however, these builders carry the consequences of an established principle to its utmost limits; they do not seem to understand those obstacles which our modern art places in the way of bold attempts in the shape of the academic veto. Construction is not for them that science which consists in saying: "Here are the rules, here are the examples, follow them out, do not go beyond them." On the contrary, Science for them says: "These "are the general principles, they are broad, they indicate nothing "but methods. In their application extend them as much as the "material and your experience allows you; we ask nothing of you "except to remain faithful to these general principles; moreover, "everything is possible to him who knows how to apply them." Is that a stationary art, hieratic, alien to the modern spirit, as they have undertaken for so long a time to make us believe? Is it retrograding to study it, to investigate it? Is it the fault of this art if very many imitate only the exterior appearance of it, if they compromise its further development by maladroit copies? Do we impute to antiquity the bad copies of its art? Why then blame the arts of the Middle Ages in France for the false applications which have been made of them, whether in Italy before the Renaissance, or at home in our own time? Since the moment when it was admitted that there was no architecture except in Italy, since the architects have flocked like sheep marching in each other's footsteps, to study their art in that country, academic instruction has been willing to see the Middle Ages only there. But the mediæval edifices in Italy, from the structural point-of-view, evince but a passable comprehension of the subject. Almost always they are nothing but constructions derived from Roman antiquity, invested with a pretty bad covering borrowed from the arts of the North or the Orient. Assuredly it is not necessary to cross the Alps to study that. For construction, there are neither settled principles nor coherence, but a disordered mass of confused traditions, influences

which combat one another, a barbarous love for luxury alongside of evident feebleness.[1]

What are these basilicas in Rome for example, reconstructed for the most part in the thirteenth century, if they are compared to the edifices built here at home at that epoch? Miserable brick walls, badly put together, on fragments and capitals torn from antique monuments. In these barbarous structures, where is the study? If we consider them with respect and curiosity, is it not because they offer us the spoils of magnificent edifices? If we marvel before rich stolen jewels, in a palace, is it the thief who excites our admiration? Let us then be sincere and put things in their right places. If the Romans of the Middle Ages found a soil covered with antique débris; if the baths of Caracalla were still standing and almost intact up to the thirteenth century, as well as the Coliseum, structures on the Palatine and so many other edifices, shall we go out of our way to admire the works of men more barbarous than the Vandals and the Huns, who have in cold blood destroyed these monuments in order to erect bad buildings, in which these débris themselves are unskilfully used, coarsely handled? We see in all this only the vanity of a powerless people; intelligence, ideas, art itself are completely wanting. What a different spectacle in this country! The lay architects in France were then laboring assiduously; without a thought for their personal glory, they sought only to develop the principles which they had discovered; they believed that the future was theirs and this was not an illusion, for they were the first to commence in the modern era the great struggle of intellectual

[1] A single example to show that we do not exaggerate. We have noticed in this article as a result of what persistent efforts the constructors of the North mastered the thrusts of vaults and in what conditions they were satisfied with the stability of these vaults. But, in Italy, the spreading of the arches of vaulted monuments during the Middle Ages and even the Renaissance is prevented by exposed iron bars at their springings. At this rate one can easily dispense with the whole train of flying buttresses and devices to secure equilibrium. They take good care neither to show these iron bars in the drawings which they give us, nor to speak of them in their treatises on the subject. But, in truth, is that a method of construction? Is it not rather a confession of inability?

man against brute matter. The constructors of antiquity are the allies and frequently the slaves of matter; they are subject to its laws; the lay constructors of mediæval times declare themselves its antagonists; they maintain that mind ought to gain the mastery and render it subject and that it will obey. It is indeed to be expected that we who pierce mountains so as to travel easier and faster, who no longer pay any attention to distances and who defy natural phenomena, should scorn those who, by their inquiring and subtle spirit, their disinterested faith in principles based on reason and calculation (disinterested certainly, for scarcely have the names of even a few of them come down to us) have been centuries in advance of us and who have only made the mistake of living too early, of being too modest and of having believed that other people would understand them. They tell us that history is just; we hope so; but its justice sometimes has to be waited for a long time. We admit that from the twelfth to the fifteenth century, political society is in disorder; the clergy were usurpers, the feudal lords were tyrants, kings were sometimes pliant, sometimes false and always ambitious; Jews were usurers and the peasantry were miserable brutes, that this society is permeated by ridiculous superstitions and pays little attention to morality; but we see quietly appear in the midst of this chaos a class of men who are neither monks, nobles, nor peasants, seizing upon the most abstract art — the one which lends itself to calculations, to logical developments; the art to which every one must have recourse, for it is necessary that people shall be lodged, protected, defended, shall make temples, dwellings and fortresses. We see this class attract to itself all the artisans and submit them to its discipline. In less than half a century this association of indefatigable workers discovered entirely new principles, capable of infinite extension; it has brought into all the arts analysis, reasoning, investigation, in place of routine and decrepit traditions. It establishes schools; it goes on without stopping a single day, isolated, but systematized, tenacious, subtle, in the midst

of anarchy and general indecision. It mounted the first steps of the modern industry, of which we are with good reason proud; and because of the fact that this association devotes its time to work, instead of inditing memoirs in its own praise; because its members, more solicitous of making their principles triumph than of obtaining personal glory, write their names on a few stones; that by reason of researches they even arrive at abusing these principles; because finally this association is overwhelmed under the last three centuries whose vanity at least equals their distinction, shall we be so ungrateful to-day as not to recognize what we owe it, so senseless as not to profit by its labor? And wherefore this ingratitude, and this foolishness? Because a few lazy minds secure in their positions pretend to preserve the principles of a dead art, which they take good care not to put into practice; which they do not even clearly announce? Who are the retrograde minds? Are they those who would condemn us to reproduce for ever and ever the incomplete or ill-digested attempts made by the last three centuries to regenerate the architecture of the Romans, or those who seek to restore to honor the resources of an art at once systematic and audacious, lending itself to all the combinations and to all the developments necessitated by the varying requirements of modern civilization? The balance of the history of the arts would be exact if it were held by an impartial hand, if, instead of names, deeds were put into its scales, monuments in place of individualities. What have we, in fact, to offset such names as Dioto Salvi, Arnolpho di Lapo, Brunelleschi, Michelozzo, Baltazar Peruzzi, Bramante, San Micheli, San-Sovino, Pirro Ligorio, Vignola, Ammanati, Palladio, Serlio, Jean Bullant, Pierre Lescot, Philibert Delorme, Ducerceau, and so on? Two or three names scarcely known; but if our French mediæval monuments could speak; if they could give us the modest names of their authors — if, especially in face of the works of the men we have just cited, they could show us all the mysteries of their construction, then assuredly history would do them justice and we should cease to be the dupes,

to our own detriment, of a mystification which has lasted through more than three centuries.

Occidental Europe can boast with good reason of having provoked the great intellectual movement of the Renaissance and we are not among those who regret this return towards the arts and the ideas of Pagan antiquity. Our century follows that of Montesquieu and Voltaire; we do not renounce those great minds, — we profit by their perspicuity, their love for truth, reason and justice; they have opened the way for criticism, they have extended the domain of intelligence; but what do they teach us? Is it, perchance, to subject ourselves eternally reproducing their ideas, to conform ourselves without scrutiny to their personal tastes, to share their errors and their prejudices, for they are no more exempt than others from these? That would be to understand them very poorly. What do they say to us on every page? "Enlighten yourselves, do not stop, "put to one side opinions already made; these are almost always "prejudices; intelligence has been given to man so that he may ex-"amine, compare, collect, choose but not conclude, for to conclude is "to end; and he is a fool who pretends to say: 'I have closed the "human book!'" Is it then the particular task of a given philosopher that should be taken for a model, or his way of reasoning, his method? Voltaire does not like the Gothic, because Gothic art belongs to the Middle Ages, whose last prop he undermines: that only proves that he knows nothing of this art and that he obeys a prejudice. That is a misfortune for him; it is not a rule of conduct for artists. Let us try, if we can, to reason as he does; let us bring to the study of our art his spirit of analysis and criticism, his good sense, his ardent passion for that which he believes to be just; and we shall succeed in finding that mediæval architecture is founded on new and fruitful principles, different from those of the Romans; that these principles may be more useful to us to-day than are the Roman traditions. The rare spirits who have acquired in their times a great influence are like torches which illumine only the spot

where they are placed; they can only enlighten distinctly that which surrounds them. But shall we say that there are no more objects in the world than those on which they have shed their light? Put them in other surroundings, — they will shed upon other objects the same light. But we are thus constituted in France: we look at the illuminated objects without noticing the torch, without even transporting it elsewhere to utilize its light in examining everything. We prefer to adhere to the judgments pronounced by distinguished intellects rather than to use their method of examining facts, so as to reach our own conclusions. In truth, this is much easier. We admire their boldness, the range of their vision; but we do not dare to be bold like them, to see further than they or anything else than that which they have been willing or able to see. But we have wandered from our mediæval master-workman.

Let us come back to them, especially since they probably never suspected that it would one day be necessary to blacken so much paper, in their own land, in the endeavor to make their efforts and their progress appreciated. In advance of their century, by the breadth of their ideas and still more by their independence as artists; disdained by more enlightened centuries, who have not wished to give themselves the trouble to understand them; in truth, their destiny is hard. Will the day of justice for them never come?

The necessities of civil construction are much more varied than those of ecclesiastical construction; thus civil architecture affords the mediæval architects the opportunity of manifesting the numerous resources which are to be found in the principles by which they were governed. It is necessary to define fully these principles, for they have great importance. The architecture of the Romans (not that of the Greeks, let it be well understood)[1] is a structure clothed

[1] For those architects who have somewhat studied the arts of antiquity, the difference between the architecture of the Geeks and that of the Romans is perfectly well defined: these two arts follow opposite roads as we have said many times; but it is not so for the vulgar, who confound these two arts, just as if one was only a mere derivative from the other. How many times has it not

with a decoration which thus becomes, in virtue of the fact, architecture, visible architecture.

If one undertakes to measure a Roman monument he must perform two operations: the first consists in taking account of the methods employed to rear the carcass, the construction, the structure itself; the second to find out how this construction has taken a visible form more or less beautiful, or more or less well adapted to this body. We have elsewhere given an account of this method.[1]

This system possesses its advantages, but it is frequently nothing but a clever falsehood. Roman construction can be studied independently from Roman architecture, and that which proves this is that the artists of the Renaissance studied that exterior form without taking account of the body which it covered.

The architecture and the construction of the Middle Ages cannot be separated, for that architecture is nothing else than a form commanded by that very construction. There is not a member, however minute it be, in Gothic architecture, at the epoch when it passed into the hands of the lay-workers, which is not prescribed by a constructive necessity; and if the Gothic structure is very varied, the needs to which it must submit itself are themselves numerous and varied. We do not hope to present to the eyes of our readers all the applications of the system of civil construction among mediæval people; neither can we undertake to show in outline the principal paths followed by this system; for one of the most striking qualities of mediæval art, as of manners, is its individuality. If one undertakes to generalize, he falls into the strangest errors, in the sense that the exceptions are more important than the rule; if he undertakes to give an account of some of these exceptions, he does not

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been written, for instance, that the portal of Saint Gervais, at Paris, is a Grecian portal? It is scarcely more Greek than Roman. It is, nevertheless, on judgments as blind as this that the criticism of the arts of architecture has been based with us for a long time and that is because we, architects, perhaps from indifference, are the only ones in France who do not write about our art.

[1] See our "*Discourses on Architecture.*"

know which one to choose, and he narrows the picture. We can, we believe, bring out the principles, which are simple and rigorous and pick out from among the applications those which best and most clearly express these principles.

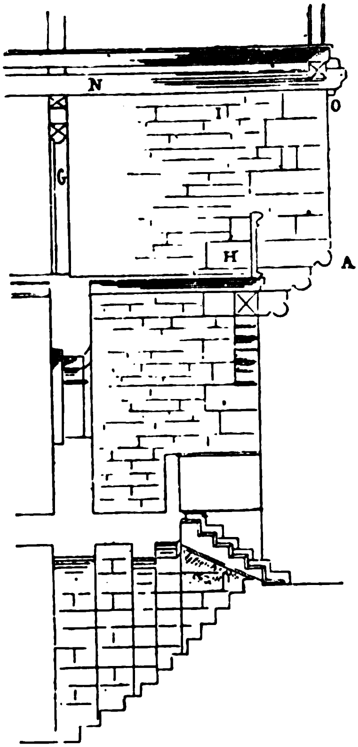
The few examples which we have given show, we hope, the consequences of the principle received by the secular architects of mediæval times: manifestation of the means used in the structure of edifices and appearances really producing architecture — that is to say the visible form; solution of the problems met, by the natural laws of statics, of equilibrium of forces and by the employment of materials in the ratio of their properties; acceptance of all programmes, whatever may be their variety and subjection of the construction to these programmes, consequently of the architecture itself, since this architecture is only the frankly-admitted appearance of this construction. Having meditated on these principles, having chosen some examples among the applications of these principles, there is no architect who cannot construct, as did these mediæval masters, proceed as they did and vary forms in proportion to the new necessities which perpetually arise in a society like ours, since each new need should provoke a new application of principles. If we should be accused of wishing to cause our art to retrograde, it would be well, at least, to have it understood in what manner we intend to pull it backwards; the conclusion of all that we have said being: "Be true." If truth is a sign of barbarity, of ignorance, we shall be happy to be classed with those who are barbarous and ignorant and proud to have drawn some of our *confrères* with us.

Corbels play an important rôle in civil constructions. We have previously given the reason; it remains for us to follow the varied applications of this method. There are, in that portion of Champagne which touches Burgundy, and *vice vêrsa*, houses otherwise very simple, constructed during the thirteenth and fourteenth centuries, which have a gable toward the street and form on the exterior a sort of porch with balcony above, sheltered by a strongly-projecting

roof. The entire system consists merely of cleverly-combined corbels. Thus (134) the side walls carry a first corbelling at right angles to them, intended to carry a bressummer receiving the ends

Fig. 134.

of the second-story floor-beams which also bear upon the recessed wall. This bressummer is surmounted by a balustrade. A second corbelling *A* gives a projection to the side walls which protects the



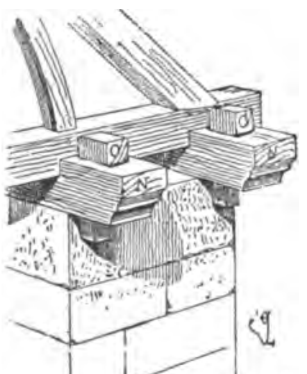


Fig. 134*b*.

balcony and receives a gable truss whose tie-beam carries the flooring of the garret and permits the introduction of provisions into it. The recessed enclosure on the line of the first-story wall is only a framing of wood roughly plastered. Notice that the second corbelling *A* (134*a*) carries above its last course *H*, a portion of vertical wall *H I*, so as to weight the ends of the corbelled stones by a mass of masonry. Further back is the wood framing *G*, which closes the second story. To avoid any chance of the corbelled mass rocking, the double plates *N*, which carry the roof, and which surmount the whole length of the side walls, are furnished on the outside with strong key-pins *O*, which maintain the head of the corbelling. This very simple arrangement is found in very many peasants' dwellings. But we will now see how the constructors reached the point of using corbellings with skill in richer, more complicated, more important structures,

while submitting themselves to dispositions demanded by a special requirement.

The problem is to pierce a doorway in the re-entrant angle, formed by two buildings which meet at right angles, a very convenient arrangement, moreover, and which was frequently insisted upon by the inhabitants of a manor or a dwelling; to arrange that this door shall give access to the ground-floor rooms on the right and left, then to the second story; to overcome the splay in which the door is cut, to recover the right angle formed by the meeting of the main walls, of which at least one will make a partition wall as it is prolonged; and to then establish above this door and in the re-entrant angle, a service staircase connecting the second story with the upper stories. By the use of iron beams covered with plaster we should to-day easily succeed in satisfying this programme. But if it is required not to falsify the construction, the thing becomes less easy. Let (135) be the plan A of the ground-floor of this construction, and plan B the second story. At C is shown the door which opens in the splayed wall; at D the interior piers; at E the horizontal projection of the interior corbels supporting the re-entrant angle and at F the horizontal projection of the

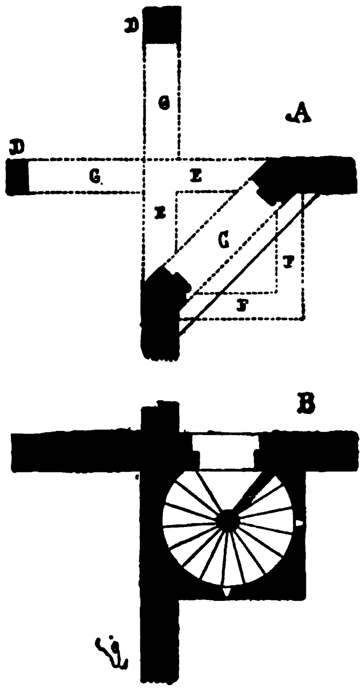


Fig. 135.

corbellings carrying the salient angle; *G G* are the arches counter-butting the re-entrant angle, and carrying the second-story partition

Fig. 136.

walls. We show (136) the exterior view of the doorway with the corbellings which act as a hood for it, and which carry the salient

angle of the service staircase shown on the second-story floor-plan *B*. If necessary, these corbellings may mask machicolations for defending the doorway. Figure 137 gives the interior view of the doorway

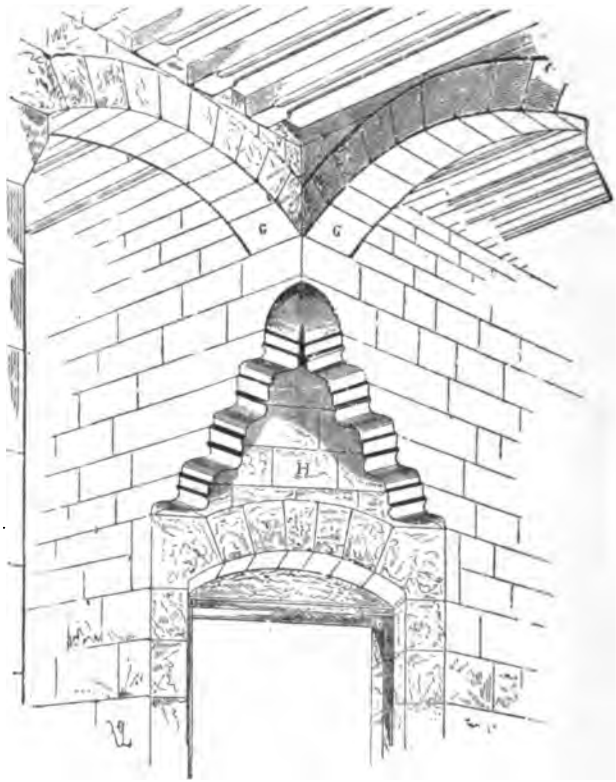


Fig. 137.

with the corbellings carrying the re-entrant angle; at *G* are the two arches counterbutting the corbellings and supporting the partition walls above. The newel of the staircase ascends in the centre *H* of the splayed wall and the interior and exterior corbellings are kept

in equilibrium by the opposing weights of the two salient angles of this staircase well. It has been attempted in later times to obtain analogous results by means of pendentives; but pendentives load the masonry below much more than this system of corbellings; require larger-sized materials and a greater amount of them; and problems in stereotomy, difficult to plot and still more difficult of execution. This then is no progress at all, unless one considers it progress to give pleasure to a stone-cutter; to show his knowledge to the detriment of the purse of him who builds.

If during the fourteenth and fifteenth centuries the ecclesiastical constructions modified but little, the methods applied to the art of building by the architects of the thirteenth century, it is not the same with civic constructions. These take on a freer manner; the processes are more elaborate, the methods more varied; the architects show proof of that independence of which they show the lack in the religious monuments. This is in reality because the current of life turned away from religious architecture and bent all its energy to civil constructions. Under the reigns of Charles V and of Charles VI, there is a rapid development of architecture applied to public edifices, to castles and to mansions. No difficulty daunts the constructor and he succeeds by carrying further the principles admitted by his predecessors in executing constructions the most daring and the most skilful from the double point-of-view of solidity and art. At that epoch a few seigneurs knew how to give an extraordinary impulse to constructions; they loved them as they should be loved, leaving to the artist perfect freedom, both in regard to the methods of execution and the character which fitted each structure.[1]

[1] Nothing strikes us as worse and more ridiculous than to wish, as happens only too frequently nowadays, to impose on architects something else than programmes; nothing gives a more gloomy idea of the state of the arts and those who profess them, than to see artists accept all the extravagances imposed by persons ignorant of practice, under the pretext that they pay the bills. Tailors have, on this score, more moral courage than many architects; for a

The Duke of Burgundy and the Duke Louis of Orleans, the brother of Charles VI, caused to be raised residences, half fortress, half palace, which indicate in the artists charged with these works a rare experience and knowledge and perfect taste; and in the seigneurs, who ordered these works, a wise and intelligent liberality which has hardly been, since that time, a peculiarity of persons sufficiently rich and powerful to undertake great works.

If Louis, Duke of Orleans, was a great spendthrift of public funds and if he abused the state of madness into which the King, his brother, had fallen, it must be admitted that, in the capacity of a wealthy seigneur, he built like a man of taste. It was he who rebuilt almost entirely the Château of Coucy, who built those of Pierrefonds and Ferté-Milon, and greatly enlarged those of Crépy and Béthisy. All the buildings undertaken by order of this prince

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good tailor will say, if one orders a ridiculous coat: "I cannot make you a garment which will disgrace my house and which will make a laughing-stock of you."

This evil dates sufficiently far back, for our good Philibert Delorme wrote about 1575:

"I desire to inform you, that for thirty-five years gone, and more, I have "observed in diverse places, that the major part of those who have made or desire "to make edifices, have begun them even so hastily as they have lightly "considered of them: thereby has resulted most often repentance and derision, which "always follow those ill-advised: in such wise, that they who think to understand "truly that which they would do, have required the contrary of that which was "possible and ought, indeed, to be done. And if by good chance they sought from "someone advice touching their resolve and undertaking, it was a master-mason, "or master-carpenter, as one is wont to do, or perhaps some painter, some "notary, or others who hold themselves for well-informed, and for the generality "have hardly better judgment and counsel than those who ask it from them— "oftentimes likewise I have seen great personages who have deceived themselves, "for as much as the most part of those who are about them, never wishing to "gainsay them or desiring to please them, or indeed, because they themselves "lack understanding, answer straightway with the words, '*It is well said, my lord;* "*it is a fine invention, it is very well imagined, and shows truly that you have an* "*excellent understanding; never will such another work be seen in the world.*' But "the flatterers think quite otherwise, and talk of it behind his back, or perhaps "elsewhere. In this wise many seigneurs cheat themselves and are satisfied with "their achievements."

We might go on and cite *in extenso* the six first chapters of the treatise of Philibert Delorme; we refer our readers to it as a masterpiece of good sense, of wisdom and probity.

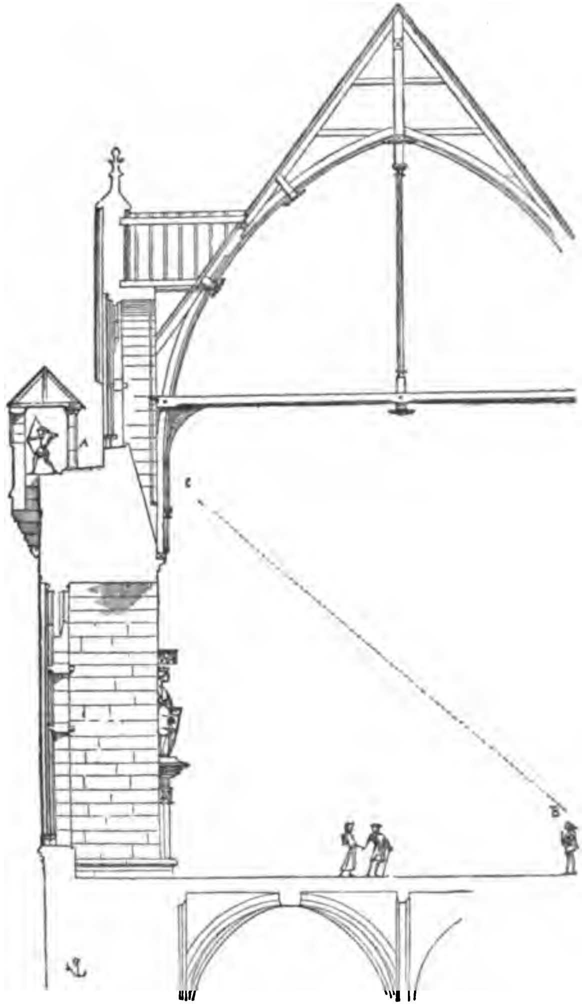


Fig. 138.

are of rare finish and rare beauty. There will be found there what are so difficult to unite in one and the same building, perfect

solidity, strength, elegance and that tasteful splendor which leaves nothing to caprice. From this point-of-view the buildings of Coucy, raised about 1400, have all the majesty of Roman buildings and all the charm of the most delicate designs of the Renaissance. Apart from the style peculiar to the epoch we have to recognize in the architects of this time a more marked superiority in construction over those of the sixteenth century; their conceptions are broader and their processes are more certain and more wise; they knew better how to subordinate details to the whole and how to build more solidly. The great Hall of the Château of Coucy, called the Salle des Preux (Hall of the Nine Worthies) is a perfect work; we can here show only some parts which relate to the subject matter of this article.

This Hall, in the second story, is above a ground floor whose vaults rest upon a row of columns and the lateral wall. It is not less than 16 metres wide and 60 metres long; that is to say, it can easily hold 2,000 persons. On one side, its windows open on the country through the thick curtain walls of the château; on the other side, on the interior court. Two enormous double chimneys warm it and the side windows are six in number, three on the outer side and three on the court, without counting an immense window to the south, opening under the soffite of the vaulted wooden roof. The side windows are also surmounted by dormer windows in the roof. We give (138) a section of this hall taken through one of the side windows with the dormer above it, and (139) an interior perspective of this same window which has not less than four metres opening. The flat arch which spans it is built of ten voussoirs set with great care which, held in place by the curtain wall, fully four metres thick, have remained horizontal without any iron framework. In the perspective view we have supposed the roof removed at *A*, so as to show from the interior the construction of the dormer window. These dormer windows (see the section) open on the broad *chemin de ronde* (footway behind the battlements) so that

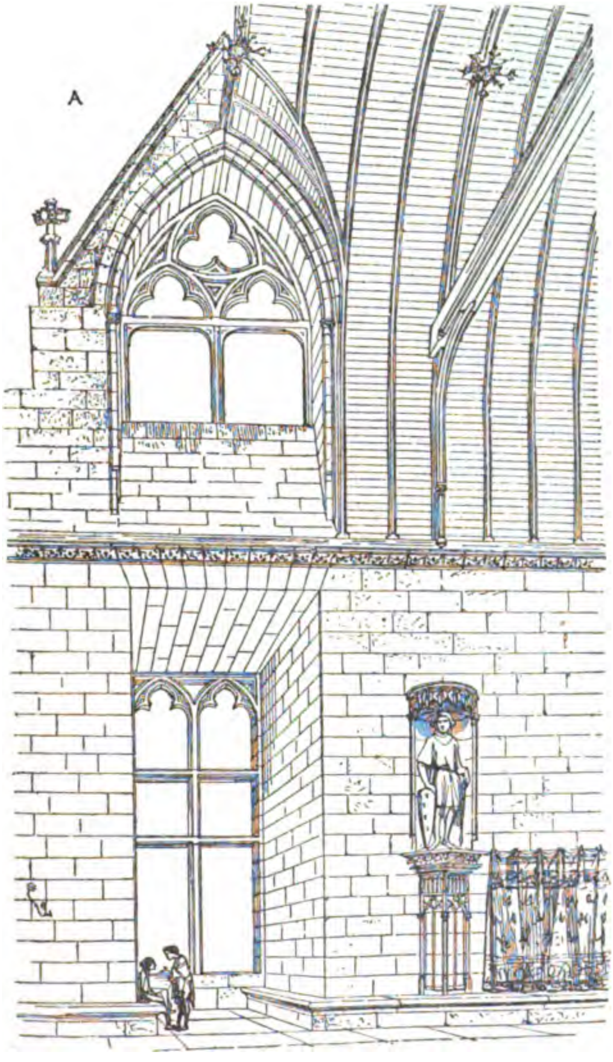


Fig. 139.

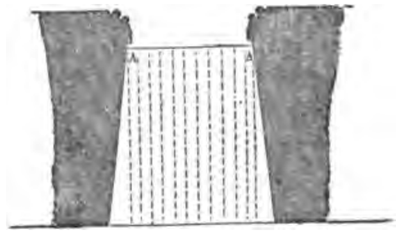
at need, the soldiers posted in this footway could speak to the persons in the hall. The defenders were sheltered under a little roof supported by the battlements and isolated piers A. Daylight, then, entered the hall through the dormer windows without hindrance and this construction is on so great a scale that from B in the hall, one could not see the top of the roof of the *chemin de ronde* as is shown by the dotted line BC[1].

No trace of the roof remains and nothing is found to-day of all this noble construction, except the windows and the lower part of the dormers, which are enough, however, to give an idea of the stately arrangements. In the hall of the Salle des Preuses (hall of the Female Worthies) in the same château, are still to be seen windows which are vaulted as shown in Figure 140, so as to support a considerable load of masonry. The skewbacks of the double discharging arches project over the splay as far as the impost A of the window (see the plan), so as to avoid warped surfaces in the voussoirs whose soffits are thus made parallel. The upper arch alone shows on the outer face of the wall and completely relieves the lintel.

It is understood, of course, that the constructors employed these powerful methods only in buildings of importance, less calculated to resist Time's ravages than the destructive contrivances of men. It seems even that the interiors of châteaux where there was no fear of an attack, the architects had tried to divert the occupants' eyes by very elegant and dainty forms. We know that Charles V had built in the Louvre, at Paris, a staircase and galleries which passed for masterpieces of the builders' art, and which compelled the admiration of all connoisseurs up to the time when these precious edifices were destroyed. Staircases in particular, which present innumerable difficulties to builders, excite the emulation of mediæval

[1] These great halls were habitually floored with flags; they were washed every day and gargoyles were arranged to carry off the water. "The blood of the victims ran away on every side and poured out by the openings (rigel-stein) left near the sills of the doors" (Nibelungen Lied).

architects. There was no seigneur who did not wish to have a *degré* more elegant and better designed than that of his neighbor and, in fact, the little that remains to us of these indispensable accessories of châteaux always indicates a certain pretension as well as great ability in draughting. (See *Escalier*).



Plan.

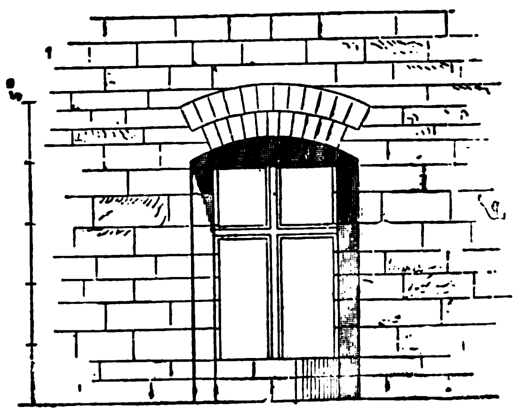


Fig. 140.

For the more modest dwellings of townspeople as well, the construction becomes during the fourteenth and fifteenth centuries, lighter, more studied. It is then that they commence to want very large windows on the public highway, still more necessary because the streets were narrow; they adroitly combine wood with stone or

brick; they endeavor to save room in interiors by diminishing the supports and by encroaching upon the public highway with projections of the upper stories; so that as a consequence, constructors had to return to timber-framing for their fronts.

We do not wish to unduly extend this article, already long enough, or to include here examples, which properly belong to other sections in this Dictionary; we have endeavored merely to indicate the profound differences separating civil from religious construction in the Middle Ages. Our readers will do well to refer for more ample details to the words: *Boutique, Charpente, Chéneau, Egout, Escalier, Fenêtre, Fontaine, Galerie, Maison, Pan-de-Bois, Plancher, Pont, Porte,* etc.

CHAPTER X.

Military Constructions.

COMPARING the military constructions of the beginning of the Middle Ages and those of the Romans, there is to be noted only a somewhat decreased perfection in the use of materials and the execution; the processes are the same; the curtain walls and the towers are merely composed of masses of rubble work, protected with a facing of small stones either rough or sparely dressed. It seems that the Normans were the first to introduce certain improvements in military works unknown before their time, and which from the eleventh century on give to these constructions a marked superiority over those which existed in Eastern Europe. The most notable among these improvements was the rapidity with which they erected their strongholds. William the Conqueror covered England and a part of Normandy in a very few years with strongholds built of masonry executed with perfect solidity which is attested by the great number of them still standing.

It is to be supposed that the Normans established on Western soil the methods in use by the Romans, that is to say, requisitions for building their fortresses and this is, indeed, in a completely subjugated country, the best method of raising massive structures requiring only large amounts of materials and many hands. There is to be found, in short, in the primitive military constructions of the Normans no trace of art; everything is sacrificed to the prime need

of defence. Buildings of this sort furnish no material for analysis; they have no interest for us, except from the defensive point-of-view, and in this aspect their particularities are described in the articles, *Architecture militaire*, *Château*, *Donjon*, *Tour*.

It is scarcely before the end of the twelfth century that we find special methods of construction applied to defensive works, forming an art by itself. For masses of rubble-work offering equal and continuous resistance, are substituted supports united by discharging arches, and thus forming in the curtain-walls as well as in the towers some parts more resistant than others, each independent of the other, so as to avoid the fall of large portions of the masonry if they were undermined. It is about this time also they attached great importance to the site of military works, that constructors chose rocky soils difficult to undermine, and that they frequently benched out the rock in order to obtain indestructible escarpments, for during the grand sieges undertaken at this epoch, notably by Philip Augustus, sapping and mining were the means most often employed for overthrowing walls. (See *Siége*.)

One of the bas-reliefs which decorate the western façade of Notre-Dame-la-Grande at Poitiers, which dates from the commencement of the twelfth century, shows us already city walls, composed of discharging arches carried by slightly projecting exterior buttresses (141). But it is not necessary to stop too long over these representations of monuments which do not always conform to reality. The discharging arches when they exist habitually appear on the interior of the walls to carry the *chemin de ronde* and masked by the exterior facing. Common sense would, in fact, indicate that discharging arches on the exterior would mark to besiegers the point where they should begin to undermine, and that the projection of the buttresses would hide the advance guard. The above examples should therefore be considered as the reverse of the wall used on account of necessities of sculptural decoration.

The intelligence which we see displayed by the French constructors

toward the end of the twelfth century in religious and civil edifices is also found in military edifices; they endeavor to replace the passive forces of Roman construction by active forces; but military architecture is concerned not alone with existing exterior agencies

Fig. 141.

and the natural laws of gravity; it has to offer resistance to the destructive hands of men.

The logic of the artists who develop the art of architecture in the Middle Ages and raise it out of the Romanesque rut, is rigorous;

we have had occasion to demonstrate this to our readers in the first two parts of this article. It will be understood that this logical and truthful spirit found a fine chance to exercise itself in the construction of military edifices, where everything must be sacrificed to the necessity of defence. Sapping and mining carried out by means of a system of shoring, which was set on fire, being the most ordinary

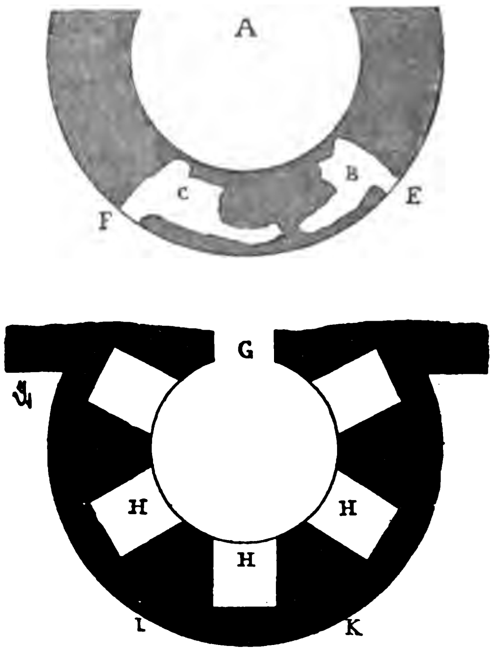


Fig. 142.

principle of attack in the twelfth century, it was necessary to oppose this system by a principle capable of rendering futile the works of the assailants. If, then (142), we construct a tower on the plan *A*, and if the miners succeed in attacking it, in two adjacent points of the exterior face, and make the two cavities *B C* shoring them with small struts, when they set these struts on fire, all the portion *E F*

of the tower will fall outside and the work will be destroyed; but if, using the same cubic quantity of materials and covering the same superficies, we take the trouble to build in place of a solid wall a series of niches included between interior buttresses as plan *G* indicates, there is an even chance that the miner will happen upon a void instead of a solid, and then his plan of burning struts will produce no results; but if he hits upon a solid wall this will offer him a greater thickness than in the plan *A*, and his work will be longer and more difficult; in addition, the recesses *H* allow of countermining, if he works below these niches. In addition, the niches *H* themselves can be shored on the inside, so as to make the fall of a part of the tower impossible, even admitting that the excavations of the mine have been made at *I*, and at *K* underneath the piers. Thus as early as the end of the twelfth century with a cubical quantity of materials equal to that previously employed and even a less quantity, the military constructors had succeeded in giving a much stronger foundation to their works. In addition, the constructors buried in the thickness of the walls tough pieces of wood bolted together with iron so as to encircle their towers at different levels. The principle was excellent but the method very bad; for these pieces of wood completely deprived of air, rapidly dried and rotted. Later they noticed the rapid destruction of wood so used and replaced it by a system of anchors made of iron cramps built in between two courses (see *Chaînage*).

There is one observation which might occur to any one and which is not devoid of interest. The mortars generally employed during the twelfth century and the beginning of the thirteenth, in churches and most religious constructions are bad, wanting in body, imperfectly mixed and frequently even the sand itself gives out and seems to have been replaced by stone dust; while the mortars employed in military constructions at this epoch, as well as before and after, are excellent and are frequently as good as Roman mortars; the same may be said of materials. The stones employed in the fortifications

are of a superior quality, well chosen and worked in large masses; they emphasize by contrast great negligence or painful economy in the greater part of religious constructions.

Evidently the lay noblemen when they built fortresses had kept the Roman method of requisitions and apportionments which the abbots and bishops were unable or unwilling to maintain. It would seem that the Norman seigneurs were the first to reorganize the building system employed by the Romans,[1] and their example has been followed in all the northern and western provinces. Enthusiasm produces great things, but it is of short duration. A sentiment of reaction against barbarism caused the erection of abbey churches and the vast constructions surrounding them; a desire for liberty and an awakening of faith brought about the building of cathedrals (see *Cathédrale*); but these moments of effervescence past, abbots and bishops found only a cold devotion left; hence negligence or scamping in the doing of work. With the lay nobility it could not be thus; the peasants were not asked for devoutness, they were required to do regular tasks under rigid supervision. This method was certainly the better one for the regular prosecution of considerable undertakings. So we ought not to be surprised at the hatred which has been transmitted among us from generation to generation against the feudal fortresses and the affection for their cathedrals which the people have retained through these hundreds of years. At the end of the last century it is true that many churches were destroyed, more particularly conventual churches — because these belonged to feudal establishments; but not many cathedrals have been destroyed, while all the châteaux, without exception, have been devastated — many, even, had been ruined under Louis XIII and Louis XIV. So far as we, constructors, are concerned, we have only to state here facts,

[1] In Normandy there existed during the Middle Ages a class of peasants called by the general name of *Bordiers*. These *Bordiers* were compelled to do the hardest sorts of work — among others — those connected with the building, such as the transport of materials, terracing, etc.; in other words they were masons' helpers. (See *Etud. sur la condit. de la classe agric. en Normandie au moyen âge*, par Léop. Delisle, 1851, p. 15, 20, 79, 83, and notes p. 709.)

from which each one can draw conclusions in accordance with his own manner of looking at things; we are obliged to admit that from the point-of-view of workmanship, there are found in the fortresses of the Middle Ages, uniformity and sureness of execution, a regulated progression and an attention which are wanting in many of our religious edifices.

In the construction of churches there may be noticed interruptions, boggling, frequent modifications in the original projects, which are to be explained by lack of money, more or less flagging zeal of Bishops, Canons or Abbots, new ideas which crowded into the brains of those who ordered and paid for the work. All that is benevolently laid to the account of the ignorance of the master-workman, the inefficiency of their methods.[1]

But when a powerful seigneur wished to build a fortress he was not reduced to solicit gifts from his vassals, to kindle the zeal of the lukewarm and to rely on time and his successors to complete that which he begins. He wished his château in his lifetime; his need was pressing, immediate. Richard Coeur-de-Lion stopped for nothing when he wished to build the fortress of Andelis, the Château Gaillard — neither usurpations nor sacrifices, nor coërcion, nor money; he proceeded to build the stronghold in spite of the Archbishop of Rouen, although the City of Andeli belonged to him. Normandy is put under the ban at the instigation of the King of France. The affair is carried up to the Pope who decrees a fine in favor of the prelate and raises the ban. But during these protestations, these menaces, these discussions, Richard does not lose a day; he is on the spot overseeing and spurring on the workmen; his fortress rises, and in a year it is done and well done — the scarp and the moats finished, the place in a complete state of defense and one of the strongest of the North of France. When Enguerrand III built the Château of Coucy, it was in preparation for an approaching and

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[1] For instance, it is always impressed upon us that such a cathedral was two centuries in building, without taking into account that out of these two hundred years they actually worked only ten or twenty years.

terrible struggle with his suzerain. A month of delay might frustrate his ambitious projects — hence even to-day it is evident that the enormous works carried out by his orders were prosecuted with a surprising rapidity — a rapidity that brooks no negligence. From base to summit the same materials, the same mortar, even more, the same workmen's marks were there; we have counted more than a hundred of them on the faces which are still visible. Now each workman's mark belongs to one particular stone-cutter, as is the case to-day in Burgundy, in Auvergne, in the department of Lyons.[1]

A hundred stone-cutters to-day give the following proportions of the other trades, on the bases of a construction like that of Enguerrand III:

Stonecutters	100
Draughtsmen, Fitters, Blacksmiths,	20
Mason's laborers, Derrickmen, Setters,	100
Graders, Laborers, Mortar mixers,	200
Masons and helpers	200

To supply the work-yards:

Quarrymen and lime-burners	100
Sand-diggers	25
Teamsters and helpers	50
	795

say in round numbers eight hundred (800).

Eight hundred workmen occupied entirely with masonry, presuppose an almost equal number of carpenters, iron-workers, plumbers, tile-layers, paviors, cabinet-makers and painters (for all the inside work of the Château of Coucy was painted on fresh plaster). We must then admit that there were at least sixteen hundred workmen busied in the construction of this fortress. If we examine the edifice, the uniform way in which the work is gotten out and set,

[1] The marks cut on the exposed faces by the stone-cutters were made to allow the foreman to keep track of each one's work; these marks prove that the work was paid for by the piece, by the job and not by the day (see *Corporation*); still further they indicate the number of workmen employed, for each had his own.

the perfect unity of the conception in *ensemble* and details, the uniformity of profiles, show a promptness of execution which rivals that which we see done to-day. Such activity resulting in so perfect a structure is found only by exception in religious constructions, as, for instance, the façade of Notre-Dame at Paris, in the substructure of the Cathedral at Rheims, in the nave of the Cathedral of Amiens. But these are only special cases, while in the fortresses of the

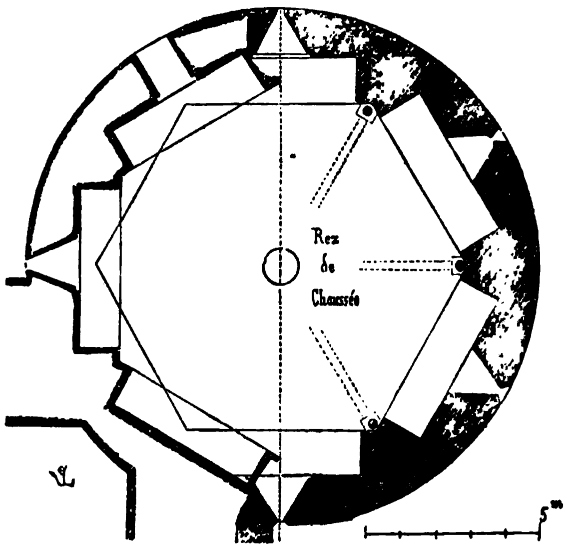

Fig. 143.

Middle Ages, from the twelfth to the fifteenth centuries, the traces of this haste may always be found at the same time with an excellent execution, well-conceived plans, studied details — no hesitation, no experiments.

Let us take, for example, one of the corner towers of the Château of Coucy, each of which are fifteen metres in diameter over all, not including the lower weatherings. Each of these towers has five

stories in addition to the roof. The lower story, whose floor is a little above the exterior grade, is vaulted in cupola form between walls whose thickness is about 3.50 metres beside the weathering. Above this story, which is nothing but a cellar intended for provisions, rises a story hexagonal within and vaulted with transverse arches.

The other stories are floored over. Figure 143 shows the superposed plans of the stories above the cellar. The piers of the hexagon are alternately placed, solids over voids, so that in perspective section we see that the abutments are built over the keys of the arches in tierce-point, forming niches between the piers as shown in Figure 144. This construction avoids the weakening which ordinarily occurs in a cylinder enclosing niches placed one above another; it also admits piercing loop-holes over-lapping one another and commanding all points of the horizon. We assume the vaulting of the lower story above the cellar to be suppressed, in order to show the general effect of the construction. Access to this cellar was had only by the circular opening pierced at the summit of the vault. It is easily seen that such a construction, resting upon a solid foundation and a lower story with very thick cylindrical walls and reinforced by an exterior talus, buttressed at each story by over-lapping piers, ought to bid defiance to all the efforts of the sapper; for, in order to overthrow a tower thus built, it would have been necessary to undermine half of its diameter, not an easy task at the top of an escarpment and in the face of a garrison commanding subterranean issues to the outworks.

Let us now examine the construction of the Keep of Coucy, built by Enguerrand III, about 1225. It is a cylinder of more than thirty metres over all with a height of sixty metres. It comprises three vaulted stories, each thirteen metres in height and a crenelated terrace. The ground-floor line is five metres higher than the bottom of the ditch, and from this interior floor-line level as far as the pavement of the ditch, the cylinder splays out conically.

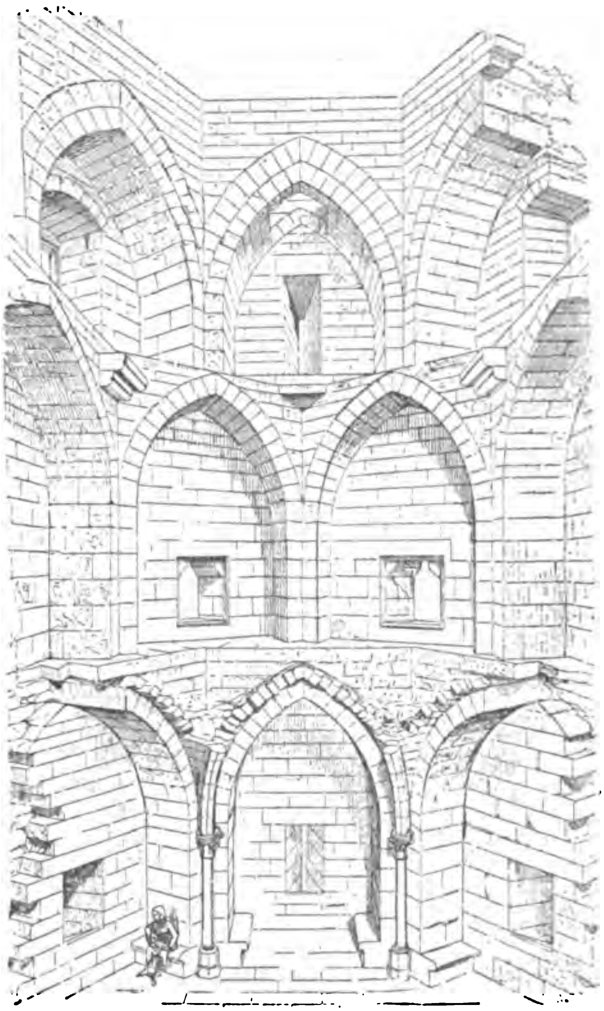

Fig. 144.

The masonry forming a solid cylinder for the height of the two lower stories is five and a half metres thick above and is further

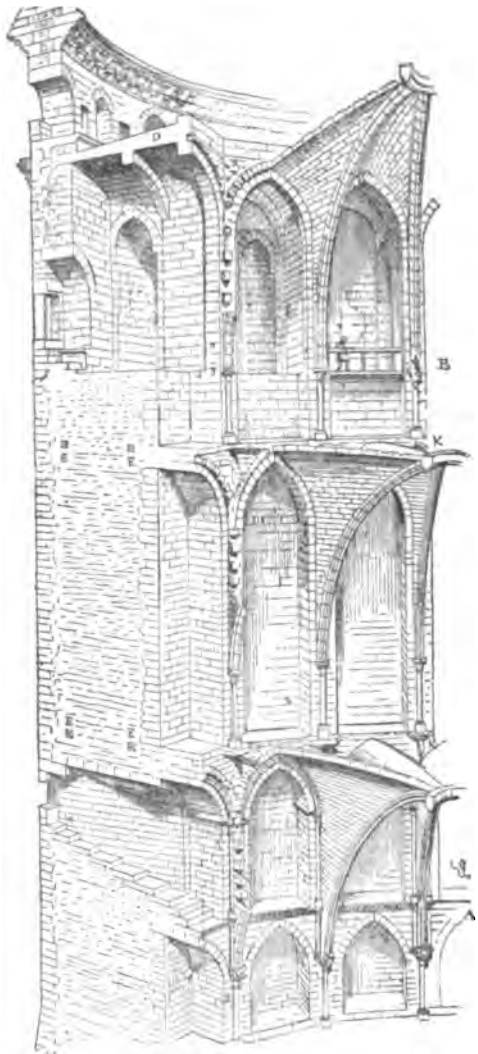

Fig. 145.

consolidated by interior piers forming twelve counterforts carrying the spandrels of the vaults (see *Donjon*).

Figure 145 gives in perspective a section of this enormous tower. The lower niches are cut through half-way of their height by the arches *A*, making out-of-the-way places for storing arms and tools. In the second story, the niches between the counterforts rise as high as the vaulting and form wall-arches for it. In the third story the construction might be made lighter; therefore the cylinder is set back

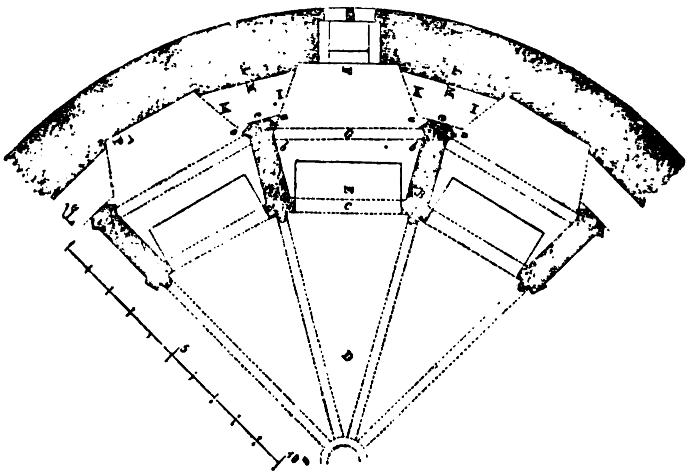

Fig. 146.

on the interior so as to form a raised gallery *B* enabling a larger number of people to assemble in the upper hall. But it is essential to explain the remarkable construction of this gallery. In plan a quarter of this story of the Keep gives Figure 146. On the twelve piers *AB* are carried the transverse overhead arches *C*, acting as wall-arches for the large central vault *D*. These piers *AB* have their two lateral faces parallel. From the points *b* spring other transverse arches *G* parallel to the arches *C*, but wider, and intersecting at their spring the skewed surfaces of the piers. On the

transverse arches *C* and *G* are sprung the pointed cradle-vaults *EF*. Other cradle-vaults *IK*, parallel to the sides *L* of the twenty-four sided polygon, rest upon the jambs *e*, on the faces *M* and on the corbelled supports *O*. The perspective section looking from the point *P* gives Figure 146*a* which explains the penetrations of the arches and vaults into the skewed vertical surfaces. The plan 146 and the perspective section 146*a* show clearly that the architects of the early part of the thirteenth century had familiarized themselves with the most complicated combinations of vaults and that they knew perfectly well how to vary the disposition of them according to the necessities of the case. We are no longer dealing with constructions. These piers which broaden out so as to bind themselves more strongly to the outer cylinder and buttress it by means of the vaults *IK* of plan 146, show very intelligent observation of the effects which can be produced in such enormous structures; and, as a matter of fact, although the engineer Metezau exploded a small mine in the centre of the stronghold in order to blow it up, he succeeded only in shooting the vaults up into the air and in cracking the tower in three different points without overthrowing it. The enormous cylinder acted like a tube charged with powder, throwing out the vaults as if they were grape-shot. This upper gallery carries a large open *chemin de ronde D* (see Fig. 145) and the central vault was roofed with lead.

At *E* (same figure) are wooden tie-beams 0.30 centimetres square forming a double dodecagon at each story and joined to radiating ties *K*, also of wood which meet at the centre of the vault. The three central vaults are each composed of twelve semicircular groins with wall-arches whose keys are placed upon the level of the central key; the triangles between the twelve groins are constructed in accordance with the ordinary method. Thus each one of the twelve bays being very narrow relatively to the diameter of the vault, it results from this that the groins only carry the radiating walls up to about two-thirds of the vault and that this central construction being

very light has, nevertheless, a powerful bracing action to the centre of the cylinder. There is no other system of vaulting outside of the Gothic system which admits such favorable treatment and this should

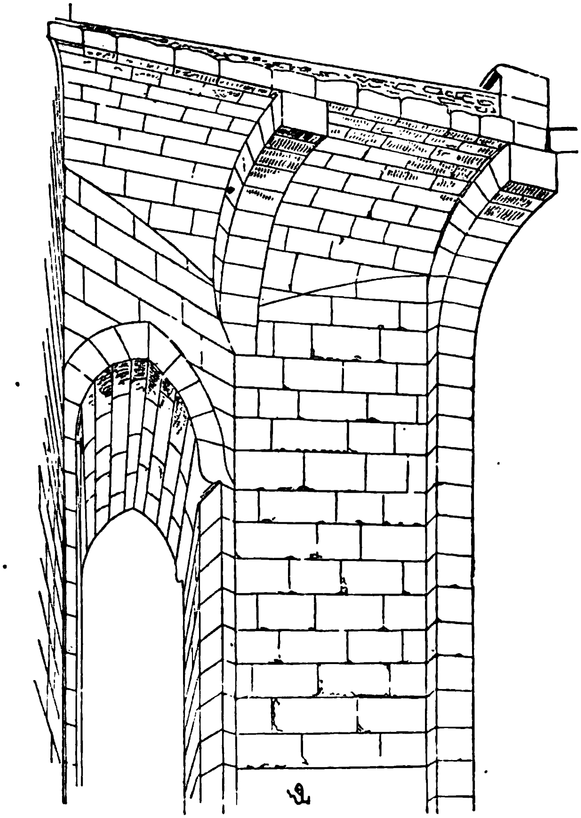

Fig. 146a.

be distinctly recognized. The whole structure from top to bottom is made of dimension stone 40 to 45 centimeters height of beds, with squared faces, roughly, but accurately dressed. In proportion as the

art of besieging places becomes more methodical, military constructions improve in character, the materials employed are larger and better selected, the walls thicker and better laid, the backing filled-in with more care and the mortar better mixed and stronger. During the thirteenth century the military constructions were made with the greatest care, the means of resistance offered to attacks singularly ample. The walls of small ashlar or rubble used during the eleventh and twelfth centuries are given up as a general thing; instead, they are made of hard dressed stone, having sufficient bearing into the wall so as not to be easily torn out by the crow-bars or pickaxes of the pioneers. In the backing are frequently found bonding courses of stones and relieving arches buried in solid masonry. The parapets are composed of through stones, the exterior surfaces admirably fashioned. As late as about 1240, it frequently happens that the courses are laid on very thick beds of mortar (0.04 to 0.05 centimetres) mixed with spawls of hard stone (147);

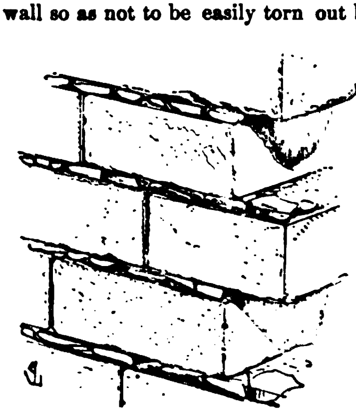

Fig. 147.

but this proceeding which gave to the beds of the courses great adhesion on account of the quantity of mortar used,[1] had the inconvenience of facilitating the introduction of the pioneer's crow-bar between the beds to detach the stones. On the contrary, dating from this epoch the beds of mortar of the courses forming the faces of fortification are thin, about 0.01 centimetres, sometimes less, the

[1] It must be remarked here that mortar has greater cohesive force in proportion to the mass employed; a very thin bed of mortar is *burned up* (as the masons say) by the stone, and becomes a powdery layer, chipped up, without adherence, because in placing the stones these rapidly absorb the water contained in the mortar, and this drying too quickly loses its quality.

edges of the stone are sharp, without spawls and their rough faces frequently form projecting bosses so as to mask the position of the beds and joints (148). It was, in fact, difficult to force the joints of stones thus faced, either by sapping, by battering rams or any of the engines made to beat down walls.

Under Philip the Bold, and Philip the Fair, military constructions fell back toward antique traditions. We have seen how the constructors of the Château of Enguerrand III, at Coucy, adopted for the towers a thick exterior cylindrical envelope, and that they used on the interior a rather light treatment to carry vaults or flooring, their slender piers enclosing between them cells arched over with pointed vaults; they seem thus to wish to reconcile the necessities of defence with the new methods of building introduced by the non-ecclesiastical architects of the early part of the thirteenth century. If in religious and civil constructions these novel principles, developed at the outset of this article, never cease to progress and develop themselves into abuse and affectation, it was not the same with military constructions; the architects came back to simpler designs, to a more homogeneous system of construction. At every step we are thus obliged to come to a stop in the study of the art of building of the artists of the Middle Ages and to start out on

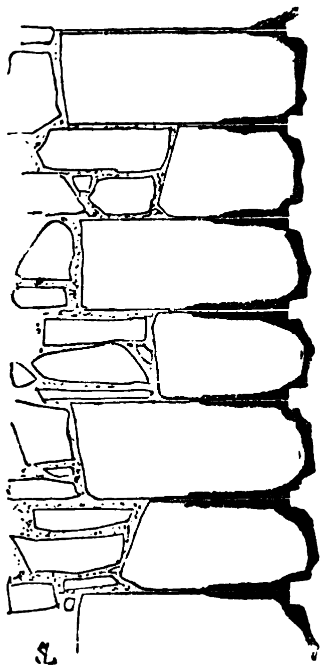

Fig. 148.

a new road; for the logical art bends itself to every exigency, to all the necessities which arise, without ever attempting to impose a routine. At the very moment when we see religious edifices exclude the semicircular arch and the art of construction abandon itself to an excess of affectation in churches, it returns in military constructions to the severest forms, to the concrete, passive system of building, to the principles, in short, so well developed by the Romans. The fortifications of the City of Carcassonne, built at the end of the thirteenth century and the beginning of the fourteenth, give us a striking example of this revolution.

As we shall have occasion to present in the "*Dictionnaire*," a

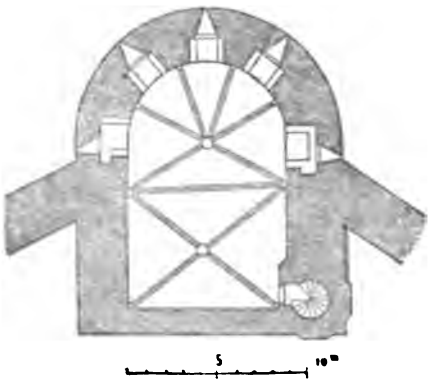

Fig. 149.

large part of the principal schemes and details of these fortifications,[1] we will here limit ourselves to giving the general plans and details of one of the most important defences of this enclosure, in order to show our readers what the art of military construction had become under Philip the Bold. We will choose the principal tower of this enclosure, the tower called *du Trésau*, which yields in no respect to the finest antique constructions with which we are acquainted. This

[1] See also the "*Archives des Monum. Hist.*," issued under the auspices of the ministry of state, by the *Commission des Monuments Historiques*. (Gide, publisher.)

tower defends one of the projections of the inner enclosure. It is constructed in accordance with the system explained in our Figure 142 (*G*), that is to say its two stories above the exterior ground-line are made up, on the side exposed to attack, of niches included between the interior buttresses, niches at the extremity of which are pierced loop-holes which command the exterior. Between stories these niches buttress one another like those in the tower of the Château of Coucy. The grade-line of the fortification is seven metres above the exterior grade. Figure 149 gives the plan of the tower *du Trésau*, on the level of the lowest story (the cellar for those within the forti-

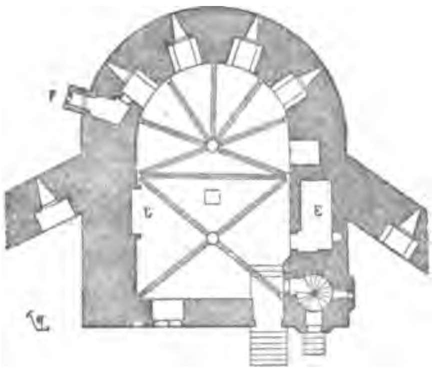

Fig. 150.

fications) on the same level as the outside grade. Under this story there was a cellar excavated in the rock faced with masonry and vaulted, access down to which was given by the cylindrical staircase in the corner of the tower. The second story (150) is raised a few steps above the level of the ground of the city. This ground-floor and this second story (ground-floor for those within the fortification) are vaulted by means of transverse arches, wall-arches and diagonal arches following the Gothic method. The second story (Fig. 150) possesses a fireplace *G*, a door opening on the parade, a lodge for the officer in charge, and privies *F*, corbelled over the

outside. The third story (second for those within the city) [151] has walls unbroken on the outside so as to strongly bind together the lower construction, whose circular wall is pierced with buttressed niches and loop-holes; this story is floored over. The fourth story (152) represents an uncovered *chemin de ronde A*, and in the centre a garret lighted by two windows in the gable wall *D*. In addition to the staircase *B*, which rises from below, there is also starting from the *chemin de ronde*, a second staircase *B'*; both of them ascend as far as the top of the two watchtowers which flank the gable *D*. Standing with your back to the gable on the flooring of the ground-

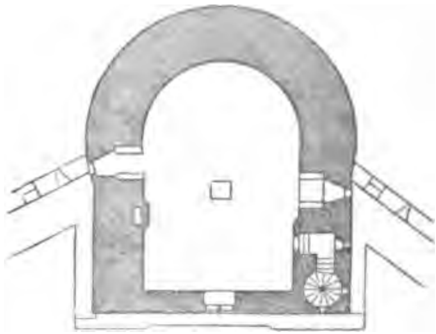

Fig. 151.

floor (plan Fig. 149), and looking outwardly, we see (153) what is the interior construction of this tower. We suppose the vault separating the lower from the second story demolished so as to show the disposition of the interior niches forming loop-holes, alternating and carrying solids over voids in order to command all points of the horizon without and also to cut the piers and avoid vertical ruptures, conformably to the system adopted in the towers of Coucy, explained above. The simplicity of this construction, its solidity, the care with which the faces are finished with beautiful cut stone, both within and without, well indicate the attention which the architects of the end of the thirteenth century gave to the execution of these constructions,

how they sacrificed all for the needs of defence, how they knew when to yield their methods to different kinds of construction.

In examining the fortifications raised about the City of Carcassonne, under Philip the Bold, we should hardly imagine, a few years later, that they would erect, in the same town, the choir of the Church of St. Nazaire, of which we have presented several portions to our readers.

The tower *du Tresau* is covered with a steep roof forming a conical hip on the side toward the country and, on the side toward the town, finishes against a gable end pierced with windows lighting the various stories. If we make a transverse section of the tower looking at the gable end, we have Figure 154.

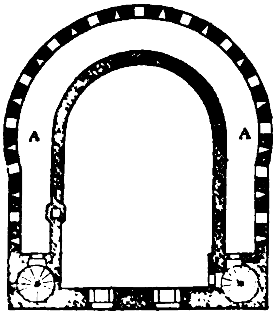

Fig. 152.

In examining the plans, we see that this gable wall has but little thickness relative to its height. But, on this side, it is necessary only to close up the gorge of the tower and this wall is, moreover solidly maintained in its vertical plane by the two watchtowers *FF*, which by their base and their weight present two points of support of great solidity. The junction of the roof with the gable is well sheltered by these steps, which form parapet walls on the interior face and which facilitate the inspection of the higher portions of the tower. The roofing (the steepness of which is indicated by the dotted line *IK*) rests upon the two supports *K*, absolutely separating the *chemin de ronde F* from the central apartment. At the level of the rampart, the *chemin de ronde G* encircles the construction on the side of the city, whose grade is at *CD*, as that without is at *AB*.

Moreover, the care employed in making a general plan of these military edifices is manifested even in the least details. We notice

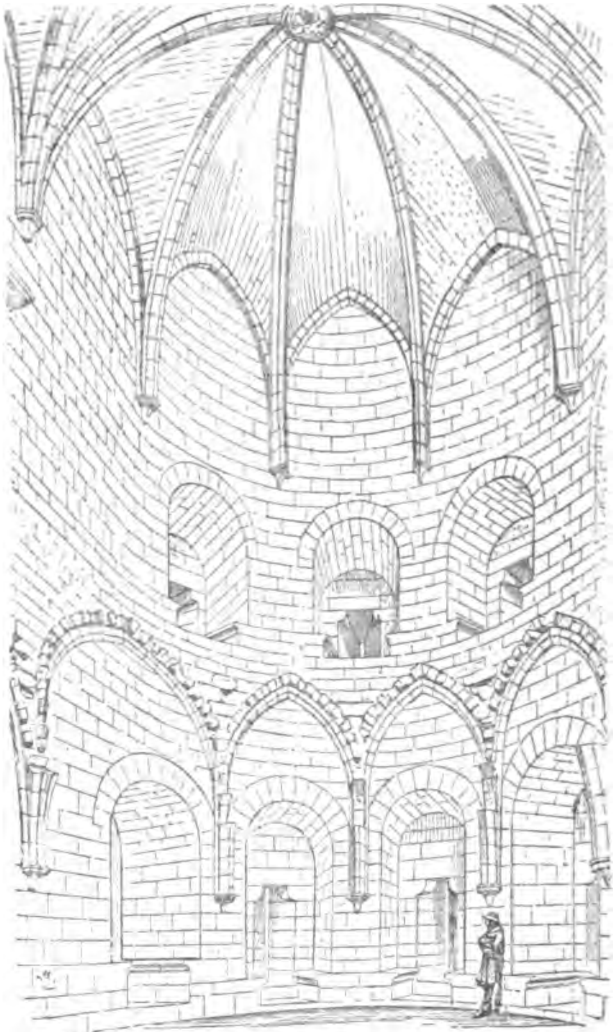

Fig. 153.

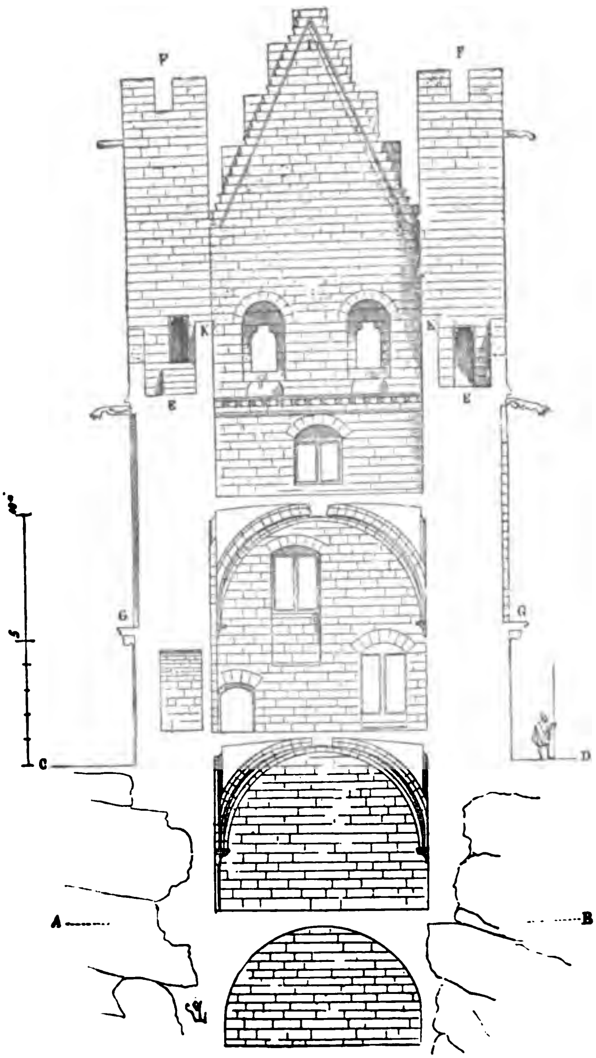

Fig. 154.

everywhere the indications of a keen observation and a consummate experience. So without enlarging too much upon the details which have their place in the articles of the "*Dictionnaire*" we shall limit ourselves to pointing out one of the interior dispositions of the structure of the fortifications of Carcassone at the end of the thirteenth century. Some of the towers, the most exposed to the efforts of the besieger, are provided on their anterior part with projecting beaks intended to keep the pioneers at a distance and to offer a strong

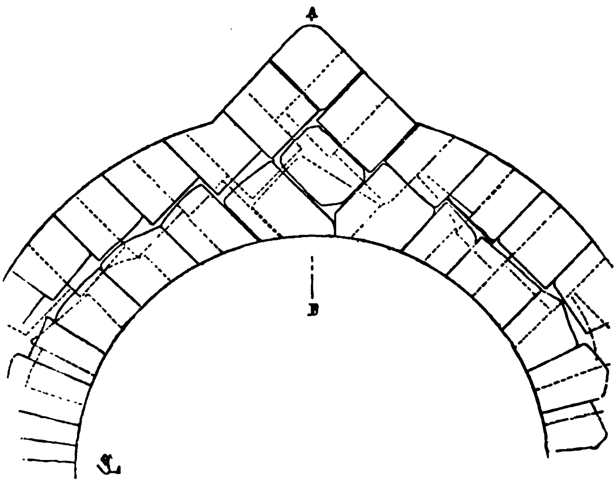

Fig. 155.

resistance to the blows of the battering ram (see "*Architecture Militaire, Tour*"). Notice, then, in this particular case how the bonding of the courses is arranged (155).

The joints of the stones on the anterior portion of the tower are not drawn normal to the curve, but at an angle of 45° relatively to the axis AB; so that the action of the battering ram on the projecting beak (the most projecting and consequently the most attackable point) is neutralized by the direction of these joints, which carry off the effect of the blows to the junction points of the tower with the

neighboring walls. If the besieger employs sappers after having undermined the beak or even beyond it, he strikes joints in the masonry which do not lead him to the centre of the tower, but give him a long and severe task, for he has to lift out with a crow-bar every block which runs obliquely, and he cannot dislodge them as easily as if they were cut wedge-shaped. In our diagram we have indicated the bonding of two courses by full and dotted lines.

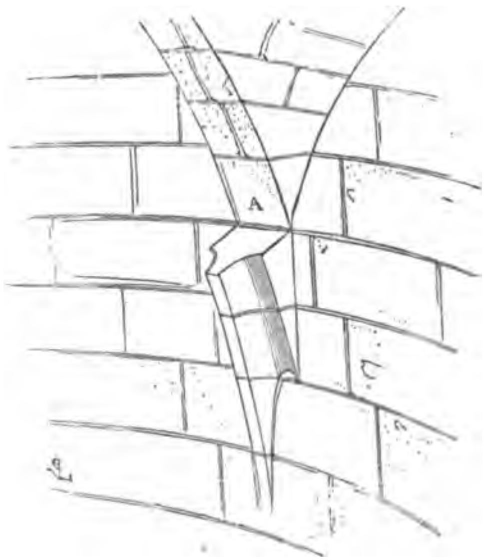

Fig. 156.

While civil and religious architecture loads itself down with superfluous ornaments, while construction becomes more and more refined during the fourteenth and fifteenth centuries, military construction on the contrary, uses each day safer methods, simpler means of obtaining greater resistance. The military construction of the end of the fourteenth century and the beginning of the fifteenth, universally employs semicircular and segmental arches; the bonding is done with particular care; the masonry of the rough

walls is excellent and they are well filled-in, which is rare in religious constructions. All useless expense is avoided. Thus, for instance, the arches of the vaults which, in the thirteenth century and again in the fourteenth are carried upon corbels, penetrate into the walls, as Figure 156 shows.[1]

The skewbacks of the transverse arch are enveloped in the courses of the interior facing of the tower. There are no more wall-arches: with good reason this member was considered superfluous. The first voussoir *A* of the haunches of the arch is cut upon the face of the wall; a simple groove cut into this wall receives the other stones which form the spandrels of the vaults. While the details of construction grow simple and less expensive, the bonding becomes better, the materials are better chosen, with regard to the place which they are to occupy; the facings are finished with extreme care even down to the foundations, for it is essential to leave no point of vantage for the work of the miner. If rock is built upon, it is benched off with all the finish usually given to the bedding of cut-stone; if the rock presents irregularities, fissures, they are made good with good courses. At all points there is recognizable that watchfulness, that attention, that scrupulousness, which are, among constructions, the usual evident signs of a very perfect art, a systematic method.

Modern artillery cut short the architects at the moment when they had pushed to its utmost limits the theory and the practice of military construction. As opposed to this, these refinements of defence became useless; it was necessary to offer to this new means of destruction enormous masses of masonry or earthworks. The cannon knocked over the covered parapets and cunningly devised machicoulations, threw down the ramparts by undermining them at the bottom and put a stop to the employment of those ingenious combinations contrived to resist attack at close quarters. Neverthe-

[1] From the towers of the Château of Pierrefonds; beginning of the fifteenth century.

less, such was the strength of many of the fortresses of the fourteenth and fifteenth centuries that systematic sieges have frequently been required to make a breech into and reduce them. In order not to extend any further this already very long article, we refer our readers for the study of the details of fortification in the Middle Ages, to the words *Architecture militaire*, *Boulevard*, *Château*, *Courtine*, *Créneau*, *Donjon*, *Échauguette*, *Machicoulis*, *Porte*, *Siége*, *Tour*.

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